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Remediation Case Studies: Groundwater Treatment

Federal Remediation Technologies Roundtable

Prepared by the

Member Agencies of the Federal Remediation Technologies Roundtable

NOTICE

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Federal Remediation Technologies Roundtable

Environmental Protection Agency
Department of Defense
U.S. Air Force
U.S. Army
U.S. Navy
Department of Energy
Department of Interior
National Aeronautics and Space Administration
Tennessee Valley Authority
Coast Guard

March 1995

FOREWORD

This report is a collection of eleven case studies of groundwater treatment projects prepared by Federal agencies. The case studies, collected under the auspices of the Federal Remediation Technologies Roundtable, were undertaken to document the results and lessons learned from early technology applications. They will help establish benchmark data on cost and performance which should lead to greater confidence in the selection and use of cleanup technologies.

The Roundtable was created to exchange information on site remediation technologies, and to consider cooperative efforts that could lead to a greater application of innovative technologies. Roundtable member agencies, including the U.S. Environmental Protection Agency, U.S. Department of Defense, and U.S. Department of Energy, expect to complete many site remediation projects in the near future. These agencies recognize the importance of documenting the results of these efforts, and the benefits to be realized from greater coordination.

There are four case study reports, organized by technology, in this series. In the future, the set will grow through periodic supplements tracking additional progress with site remediation. In addition to this report on groundwater treatment projects, the following volumes are available:

Remediation Case Studies: Bioremediation;
Remediation Case Studies: Soil Vapor Extraction; and
Remediation Case Studies: Thermal Desorption, Soil Washing, and In Situ Vitrification.

Ordering information for these and other Roundtable documents is on the following page.

Walter W. Kovalick

Walter W. Kovalick, Jr., Ph.D.
Chairman
Federal Remediation Technologies Roundtable

Ordering Instructions

The following documents are available free-of-charge from the U.S. EPA/National Center for Environmental Publications and Information (NCEPI). To order, mail or fax the completed form below to: U.S. EPA/National Center for Environmental Publications and Information, P.O. Box 42419, Cincinnati, OH 45242, or FAX requests to (513) 489-8695.

Title	Number	Price	Please Send
Abstracts of Remediation Case Studies [106pp]	EPA-542-R-95-001	Free	_______
Guide to Documenting Cost and Performance for Remediation Projects [64pp]	EPA-542-B-95-002	Free	_______

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The following documents are available by calling the National Technical Information Service (NTIS) at 703-487-4650 or writing them at: National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161

Title	Number	Price*
Remediation Case Studies: Bioremediation	PB95-182911	$17.50
Remediation Case Studies: Groundwater Treatment	PB95-182929	$17.50
Remediation Case Studies: Soil Vapor Extraction	PB95-182937	$25.50
Remediation Case Studies: Thermal Desorption, Soil Washing, and In Situ Vitrification	PB95-182945	$17.50
Remediation Case Studies: Four Document Set	PB95-182903	$67.00

Other Federal Remediation Technology Roundtable (FRTR) documents available from NTIS:

Title	Number	Price*
Accessing Federal Databases for Contaminated Site Clean-Up Technologies (3rd Edition)	PB94-144540	$17.50
Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation (3rd Edition)	PB94-144557	$17.50
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (3rd Edition)	PB94-144565	$44.50
Remediation Technologies Screening Matrix and Reference Guide (2nd Edition)	PB95-104782	$45.00

* Additional fee for shipping and handling; next day delivery also available. Major credit cards accepted.

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INTRODUCTION

The purpose of this report is to provide case studies of groundwater treatment site cleanup projects. This report is one of four volumes which are the first in a series of studies that will be prepared by Federal agencies to improve future remedy selection at contaminated sites. For projects that are ongoing, interim findings will be updated in future publications as additional data become available.

The case studies were developed by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Defense (DoD), and the U.S. Department of Energy (DOE). They present cost and performance information for full-scale remediation efforts and several large-scale demonstration projects and were prepared retrospectively, based on available information and interviews with project personnel. The case studies are meant to serve as primary reference sources, and contain information on the site; contaminants and media treated; technology and vendor; cost and performance; and points of contact for the technology application. The studies contain varying levels of detail, reflecting the differences in the availability of data and information. Full-scale cleanup efforts are not conducted primarily for the purpose of technology evaluation, and data collection is often limited to establishing compliance with contractual requirements or regulatory levels.

This volume contains reports on eleven projects, eight of which are still ongoing. Most of the projects address petroleum hydrocarbons and chlorinated aliphatics, such as trichloroethylene (TCE). The eight ongoing projects are using pump-and-treat technologies, while two of the three completed efforts utilized air sparging. One report in this volume describes a project that used in situ steam injection/electrical heating of subsurface soils (referred to as dynamic underground stripping).

Table 1 provides a project summary including information on technology used, contaminants and media treated, and project duration. The table also notes highlights of the technology applications.

Table 2 summarizes cost data, including information on quantity of media treated and contaminant removed. In addition, Table 2 shows a calculated unit cost for some projects, and identifies key factors potentially affecting project cost. While a summary of project costs is useful, it is difficult to compare costs for different projects because of site-specific factors and differences in level of detail.

Cost data are shown on Table 2 as reported in the case studies, and have not been adjusted for inflation to a common year basis. The dollar values shown in Table 2 should be assumed to be dollars for the time period that the project was in progress (shown on Table 1 as project duration).

The project costs shown in the second column of the table were compiled consistently. However, the case studies themselves vary in terms of the level of detail and format of the available cost data. Where possible, project costs were categorized according to an interagency Work Breakdown Structure (WBS).[1] The WBS specifies costs as 1) before-treatment costs, 2) after-treatment costs, or 3) treatment costs. (Table 2 provides some additional information on activities falling under each category.) In many cases, however, the available information was not sufficiently detailed to be broken down in this way.

The column showing the calculated treatment cost provides a dollar value per unit of soil or groundwater treated and, if possible, per pound of contaminant removed. Note that comparisons using the information in this column are complicated by the fact that calculated costs may only be available on a per cubic yard or per ton basis, and cannot be converted back-and-forth due to limited availability of soil bulk density data.

Key factors that potentially affect project costs include economies of scale, concentration levels in contaminated media, required cleanup levels, completion schedules, and hydrogeological conditions. It is important to note that several projects in the case study series represent early applications, and the costs of these technologies are likely to decrease in the future as firms gain experience with design and operation.

Abstracts and On-Line Access

The case studies have been summarized in abstracts which precede each study and provide key project information in a consistent format. The abstracts are based on recommended terminology and procedures from the Guide to Documenting Cost and Performance for Remediation Projects.

The case study abstracts are also available on-line through EPA's Cleanup Information Bulletin Board System (CLU-IN). To access CLU-IN by modem, call (301) 589-8366, or to contact the CLU-IN help desk, call (301) 589-8368. CLU-IN is available on the Internet; the telnet address is clu-in.epa.gov or 134.67.99.13.

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[1]Additional information on the contents of the Work Breakdown Structure and on whom to contact for WBS and related information is presented in the Guide to Documenting Cost and Performance for Remediation Projects - see ordering instructions on page iii.

Table 1. Summary of Remediation Case Studies: Groundwater Treatment

Site Name, State (Technology)	Contaminants Treated: BTEX and/or TPH	Chlorinated Aliphatics	Non-chlorinated Aliphatics	Polychlorinated Biphenyls	Source of Contamination (Principal Contaminants)	Media (Quantity)	Project Duration	Highlights
Amcor Precast, UT (Density Driven Sparging)	●				UST (diesel and gasoline)	Soil (not available) Groundwater (not available)	3/92 - 9/93	Treatment process combines aerobic biodegradation and in situ air sparging
Amoco Petroleum Pipeline, MI (Extraction followed by GAC)	●		●		Petroleum pipeline (BTEX and MTBE)	Groundwater (775 million gallons in 5 years)	Operational since 10/88	Large-scale voluntary cleanup of groundwater and free product; 118,000 gallons of free product recovered in 6 years; cleanup included air sparging pilot testing
Commencement Bay, South Tacoma Channel Well 12-A Superfund Site (Extraction followed by GAC)		●			Storage drums (PCA)	Groundwater (282 million gallons in 6 years)	Operational since 1988	Project completed in conjunction with SVE of vadose zone soils
Ft. Drum, Fuel Dispensing Area 1595, NY (Extraction followed by air stripping and GAC)	●				UST (gasoline and No. 2 fuel)	Groundwater (not available)	Operational since 2/92	Free product recovery where precise source of contamination could not be found
Langley Air Force Base, IRP Site 4, VA (Extraction followed by air stripping)	●				UST (JP-4 fuel)	Groundwater (not available)	Operational since 7/92	Vacuum-assisted well point extraction system to remove groundwater and free product
Lawrence Livermore National Laboratory, GSA, CA (Dynamic underground stripping)	●				UST (leaded gasoline)	Soil and groundwater (not available)	11/92 - 12/93	Field demonstration of steam injection, electrical heating, and underground imaging
McClellan Air Force Base, Operable Unit B/C, CA (Extraction followed by air stripping)		●			UST, landfill (TCE)	Groundwater (660 million gallons in 7 years)	Operational since 1988	Large-scale cleanup; 7 extraction wells; waste soürces included landfill, UST, disposal pit, burn area
Twin Cities Army Ammunition Plant, MN (Extraction followed by air stripping)		●			Discharges to sewer, dumping and burning (TCE)	Groundwater (1.4 billion gallons 10/91 - 9/92)	Operational since 10/87	Large cleanup effort; complex hydrogeology; estimated time for remediation 50 to 70 years
U.S. Department of Energy Kansas City Plant, MO (Extraction followed by advanced oxidation processes)	●	●		●	Manufacturing (TCE)	Groundwater (11.2 million gallons in 1993)	Operational since 1983	Extracted groundwater treated using low and high intensity ultraviolet, ozone, and peroxide; presence of DNAPLs suspected
U.S. Department of Energy Savannah River Site, A/M Area, SC (Extraction followed by air stripping)		●			Surface impoundment (TCE)	Groundwater (198 million gallons per year)	Operational since 9/85	Groundwater contamination covers 1,200 acres at a thickness of 150 feet with presence of DNAPLs confirmed
U.S. Department of Energy Savannah River Site, M Area, SC (In situ air stripping)		●			Surface impoundment (TCE)	Groundwater (not available) Soil (not available)	Operational since 7/90	Field demonstration of air sparging using horizontal wells; report discusses experience with installation of horizontal wells

Key:

GAC - Granular Activated Carbon
SVE - Soil Vapor Extraction

BTEX - Benzene, Toluene, Ethylbenzene, and Xylene
TPH - Total Petroleum Hydrocarbons

Table 2. Remediation Case Studies - Summary of Cost Data for Groundwater Treatment Projects

Site Name, State (Technology)	Project Cost ($)*	Quantity Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Project Costs
Amcor Precast, UT (Density-Driven Sparging)	C - 156,950 O - 62,750	Not available	Not available	--	Cleanup completed in approximately 18 months
Amoco Petroleum Pipeline, MI (Extraction followed by GAC)	C - 297,000 (for groundwater recovery and treatment system) (includes design and engr.) C - 375,000 (for air sparging system) O - 475,000	775 million gallons of groundwater in 5 years	118,000 gallons free product recovered	Ongoing full-scale cleanup; O&M to date approximately $0.003 per 1,000 gallons of groundwater treated	--
Commencement Bay, South Tacoma Channel Well 12A Superfund Site (Extraction followed by GAC)	C - 1,343,701	282 million gallons in 6 years	10,361 pounds of VOCs	Ongoing full-scale cleanup	--
Ft. Drum, Fuel Dispensing Area 1595, NY (Extraction followed by air stripping and GAC)	C - 958,780 (includes design and engr.) O - 129,440 (estimated)	Not available	Not available	Ongoing full-scale cleanup	--
Langley Air Force Base, IRP Site 4, VA (Extraction followed by air stripping)	C - 569,739 O - 216,561 (1993) O - 143,047 (1994)	Not available	Not available	Ongoing full-scale cleanup	16 extraction wells; low hydraulic conductivity
Lawrence Livermore National Laboratory, CA (Dynamic underground stripping)	T - 8,740,000 (includes design and engr.) B - 1,700,000	Not available	7,600 gallons of gasoline	Field demonstration project	Complex hydrogeology and wide range of hydraulic conductivity; demonstration completed in approximately one year
McClellan Air Force Base, Operable Unit B/C, CA (Extraction followed by air stripping)	C - 4,000,000 O - 1,240,000	660 million gallons of groundwater in 7 years	Approximately 44,000 pounds VOCs removed in 7 years	Ongoing full-scale cleanup; $80 in operating costs per lb of VOC removed (first year of operation data only)	10 extraction wells

Project Cost*
T = Costs for treatment activities, including preprocessing, capital equipment, operation, and maintenance
B = Costs for before-treatment activities, including site preparation, excavation, and sampling and analysis
A = Costs for after-treatment activities, including disposal of residuals and site restoration
C = Capital costs
O = Annual operating costs

Calculated Cost for Treatment**
**Calculated based on costs for treatment activities (T): excludes costs for before- (B) and after- (A)treatment activities. Calculated costs shown as "Not Calculated" if an estimate of treatment costs unavailable.

Table 2. Remediation Case Studies - Summary of Cost Data for Groundwater Treatment Projects (Continued)

Site Name, State (Technology)	Project Cost ($)*	Quantity Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Project Costs
Twin Cities Army Ammunition Plant, MN (Extraction followed by air stripping)	C - 8,034,454 (includes design and engr.) O - 588,599	Not available	Not available	Ongoing full-scale cleanup; O&M to date calculated as $0.12 per 1,000 gallons treated	Complex hydrogeology and wide range of hydraulic conductivity at site
U.S. Department of Energy Kansas City Plant, MO (Extraction followed by advanced oxidation processes)	C - 1,383,400 O - 355,200 (actual costs for FY 1987 to 1994)	11.2 million gallons groundwater treated (1993)	Not available	Ongoing full-scale cleanup; AOP operating costs for second generation system projected as $13.80/1,000 gallons	Presence of DNAPLs suspected; use of AOP more expensive than air stripping
U.S. Department of Energy Savannah River Site, SC (Extraction followed by air stripping)	C - 4,103,000 O - 149,200 (1985 to 1990)	198 million gallons of groundwater per year	273,300 pounds VOC removed (1985-1993)	Ongoing full-scale cleanup; O&M to date approximately $0.75 per 1,000 gallons treated	Complex hydrogeology; recent discovery of DNAPLs prompted a reevaluation of pump and treat
U.S. Department of Energy Savannah River Site, M Area, SC (In situ air stripping)	Projected costs - equipment 253,525 (includes system design and engr.); site work - 5,000; labor - 62,620; and consumables - 157,761	Not available	16,000 pounds VOCs removed in demonstration	Field demonstration; projected costs of $15.60/lb of VOC removed	This demonstration project quantified cost advantage of air sparging over pump and treat; installation costs for horizontal wells greater than for vertical wells

Project Cost*
T = Costs for treatment activities, including preprocessing, capital equipment, operation, and maintenance
B = Costs for before-treatment activities, including site preparation, excavation, and sampling and analysis
A = Costs for after-treatment activities, including disposal of residuals and site restoration
C = Capital costs
O = Annual operating costs

Calculated Cost for Treatment**
**Calculated based on costs for treatment activities (T): excludes costs for before- (B) and after- (A)treatment activities. Calculated costs shown as "Not Calculated" if an estimate of treatment costs unavailable.

GROUNDWATER TREATMENT CASE STUDIES

Density-Driven Groundwater Sparging at Amcor Precast Ogden, Utah

Density-Driven Groundwater Sparging at Amcor Precast, Ogden, Utah

Site Name: Amcor Precast **Location:** Ogden, Utah	**Contaminants:** Benzene, Toluene, Ethylbenzene, Total Xylenes (BTEX), Naphthalene, and Total Petroleum Hydrocarbons (TPH) <u>Groundwater</u> - Average groundwater concentrations (mg/L) in plume area/site maximum - TPH (51/190), benzene (1.3/4.7), toluene (2.4/9.4), ethylbenzene (0.78/2.7), total xylenes (2.5/8.0), naphthalene (0.18/0.63) <u>Soil</u> - Average soil concentrations (mg/kg) in plume area/site maximum - TPH (555/1,600), benzene (2.0/7.8), toluene (1.4/2.5), ethylbenzene (5.7/19), total xylenes (37/110)	**Period of Operation:** March 1992 to September 1993 **Cleanup Type:** Full-scale cleanup
Vendor: Todd Schrauf Wasatch Env., Inc. 2251B West California Ave. Salt Lake City, UT 84104 (801) 972-8400 **SIC Code:** Not Available	**Technology:** In situ Density-Driven Groundwater Sparging and Soil Vapor Extraction - System consists of three main components - groundwater sparging system; groundwater recirculation system; and soil vapor extraction system - Groundwater sparging was principal method of remediation; SVE was used locally <u>Sparging System</u> - Density-driven groundwater sparging - removed petroleum hydrocarbons using (1) aerobic degradation and (2) in situ air stripping; water inside the wellbore was aerated directly by injecting air at the base of the wellbore - 12 groundwater sparging wells installed to a depth of 18 feet <u>Groundwater Recirculation</u> - 3 downgradient extraction (pumping) wells installed to a depth of 20 feet and 1 upgradient injection galley (former tank excavation backfilled with pea gravel) <u>SVE</u> - 3 vertical extraction wells located adjacent to the pumping wells - Vapor discharged to atmosphere	**Cleanup Authority:** State: Utah Department of Environmental Quality, Division of Response and Remediation (DERR) **Point of Contact:** Shelly Quick Utah DERR
Waste Source: Underground Storage Tanks	**Type/Quantity of Media Treated:** Groundwater and Soil - Site stratigraphy - interbedded silty sand and poorly graded fine gravel underlain by a silty clay aquitard at a depth of approximately 18 feet below ground surface - Depth to groundwater - 5 to 11 feet; aquifer thickness (7-13 feet) - Porosity (20-35%), hydraulic conductivity (190 ft/day) - Aerial extent of the plume - approximately 30,000 ft^2; vertical extent of contamination - contaminants concentrated in vertical zone from approximately 5 to 11 feet below ground surface - Estimated volume of contaminated soil - 7,000 yd^3	

Purpose/Significance of Application:
Full-scale remediation of groundwater contaminated with diesel and gasoline fuels using in situ density-driven groundwater sparging and soil vapor extraction.

Density-Driven Groundwater Sparging at Amcor Precast, Ogden, Utah (Continued)

Regulatory Requirements/Cleanup Goals:
- Soil - DEQ Recommended Cleanup Levels (RCLs) - TPH - 30 mg/kg; Benzene - 0.2 mg/kg; Toluene - 100 mg/kg; Ethylbenzene - 70 mg/kg; Xylenes - 1,000 mg/kg; Naphthalene - 2.0 mg/kg
- Groundwater - BTEX and naphthalene to below MCLs; no cleanup goal for TPH in groundwater
- Air - no air discharge permit was required because air emissions were below de minimis standards of the Utah Division of Air Quality

Results:
- The cleanup goals were achieved for all contaminants of concern in both soil and groundwater

Cost Factors:
- Total Capital Cost: $156,950 (including drill/install wells and sparging system, start-up, project management)
- Total Annual Operating Cost: $62,750 (including electricity, maintenance, monitoring)

Description:
Amcor Precast in Ogden, Utah, stored gasoline and diesel fuel in three underground storage tanks. A release was discovered in 1990. An investigation in 1991 indicated that the areal extent of groundwater contamination was approximately 30,000 ft^2 and that an estimated 6,700-7,000 yd^3 of soil had been contaminated. The primary contaminants of concern were benzene, toluene, ethylbenzene, and xylenes (BTEX), naphthalene, and total petroleum hydrocarbons (TPH). A density-driven groundwater sparging system and soil vapor extraction (SVE) system were installed in January/February 1992 and operated from March 1992 to September 1993. The sparging system was used as the primary remediation technology. SVE was used locally to treat volatilized hydrocarbons, created by the air stripping process, and prevent contaminants from migrating to nearby office buildings.

With the density-driven groundwater sparging system at Amcor, water inside the wellbore was aerated by injecting air into the base of the wellbore (rather than injected under pressure) with the resulting injection air bubbles stripping contaminants from the water while increasing the dissolved oxygen content. In addition, the aeration process acted to create groundwater circulation and transport. Therefore, with this system, petroleum hydrocarbons were removed from the subsurface by (1) aerobic biodegradation resulting from the supply of oxygen to the saturated zone; and (2) in situ air stripping. The air stripped vapors are transferred to the vadose zone and are biodegraded in place. The application of density-driven groundwater sparging and SVE achieved the specified cleanup goals for both soil and groundwater. The cleanup goals for soil and for all contaminants except naphthalene in groundwater were achieved within 11 months of system operation. The cleanup goal for naphthalene in groundwater was achieved within 18 months.

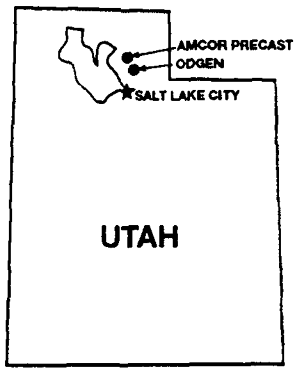
The total capital cost for this application was about $157,000 and total annual operating costs were $62,750. Air sparging is limited to contaminants that can be degraded by indigenous bacteria under aerobic conditions. Maximum sparging well air flow and groundwater wellbore circulation rates are dependent on well diameter, depth to groundwater, and the hydraulic conductivity of the formation. Therefore, longer remediation times or a greater number of sparging wells may be required in lower permeability formations.

TECHNOLOGY APPLICATION ANALYSIS

SITE

Name: Amcor Precast

Location: Ogden, Utah (directly adjacent and south of Ogden Defense Depot)



TECHNOLOGY APPLICATION

This summary addresses the field application of density-driven groundwater sparging for the *in situ* remediation of an underground storage tank release of diesel and gasoline fuels. The system was started up in March, 1992 and remediation completed in September, 1993.

SITE CHARACTERISTICS

Site History/Release Characteristics

- Amcor Precast operated three underground storage tanks at the site, used for the storage of unleaded gasoline, leaded gasoline, and diesel fuel, respectively.
- The release was discovered when the underground storage tanks were removed for permanent closure in December, 1990. The volume of the release is unknown. The exact cause of the release is also unknown, although laboratory analysis of contaminated soils from the tank excavation indicated the release consisted primarily of gasoline, with minor amounts of diesel.
- At the time of discovery and investigation (1991), the spill had an areal extent of approximately 30,000 ft^2 and had impacted an estimated soil volume of 6,700 yd^3.
- The remedial system was installed in January and February of 1992. The system was placed in to operation in March of 1992. The remediation was completed in September of 1993.

Contaminants of Concern

- The contaminants of concern were the aromatic hydrocarbons: benzene, toluene, ethylbenzene, total xylenes, and naphthalene as well as total petroleum hydrocarbons (TPH)

TABLE 1: CONTAMINANT PROPERTIES						
Property	Units	Benzene	Ethylbenzene	Toluene	o,m,p-Xylene	Naphthalene
Empirical Formula		C_6H_6	C_8H_{10}	C_7H_8	C_8H_{10}	$C_{10}H_8$
Density @ 20°C	gm/cm^3	0 88	0 87	0 87	0 86 to 0 88	1 16
Melting Point	°C	5 5	-95	-95	-47.9 to 13.3	80 5
Boiling Point	°C	80 1	136.2	110 6	138.3 to 144 4	217.9
Vapor Pressure (25°C)	mm Hg	95	10	31	6.6 to 8.8	0 23, 0.87
Vapor Density (25°C)	g/L	3 19	4 34	3 77	4 34	
Henry's Law Constant	atm-m^3/mol	5.4 x 10^{-3}	0 0064 to 0 0087 (avg. 0 0072)	0 0067	0 0050 to 0.0071	0.00036 to 0 0012 (avg. 0 00061)
Water Solubility (25°C)	mg/1	1696 to 1860 (avg. 1770)	131 to 206 (avg 174)	492 to 627 (avg. 545)	156 to 204	20.3 to 40 0 (avg 31 0)
Octanol-Water Partition Coefficient (K_{ow})		36 to 141 (avg. 110)	1120 to 1410 (avg 1290)	129 to 631 (avg. 417)	589 to 1580	1020 to 50,100 (avg. 2560)
Organic Carbon Partition Coefficient (K_{oc})	ml.gn	49 to 100 (avg. 81)	95,257	114,151	129 to 1580	550 to 3310 (avg. 1550)
Ionization Potential	eV	9.25, 9 56	8.76, 9.12	8.82	8.44 to 8 58	8.14, 8.26
Molecular	gms	78.11	106.17	92.14	106.17	128.18

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Nature and Extent of Contamination

Site investigations were conducted during the first eight months of 1991 to define the extent of soil and groundwater contamination. These investigations included soil gas surveys, drilling and sampling of soil borings, and monitor well installation and sampling. Sampling locations and plume extent are shown in Figure 1. The maximum and average concentrations of the contaminants of concern are identified in Table 2 for both soil and groundwater. Average groundwater concentrations are based on samples collected from wells MW-3, MW-4, MW-5, and MW-7, all located along the centerline of the contaminant plume. Average soil concentrations are based on samples collected from BH-3, BH-13, BH-14, and MW-5, also all located within the center of the plume. The aerial extent of the plume was approximately 30,000 ft^2. The volume of contaminated soil was estimated at 7,000 yd^3.

TABLE 2 SUMMARY OF PRE-REMEDIIATION CONTAMINANT CONCENTRATIONS						
Contaminant of Concern	Soil Concentrations (mg/kg)			Groundwater Concentrations (mg/l)		
	Site Maximum	Average in Plume Area	Cleanup Goal (RCL's)	Site Maximum	Average in Plume Area	Cleanup Goal (MCL's)
TPH	1600	555	30	190	51	Not Established
Benzene	7 8	2 0	0 2	4 7	1 3	0 005
Toluene	2 5	1 4	100	9 4	2 4	1 0
Ethylbenzene	19	5 7	70	2 7	0 78	0 7
Total Xylenes	110	37	1000	8 0	2 5	10
Naphthalene	Not Measured	Not Measured	2 0	0 63	0 18	0 020

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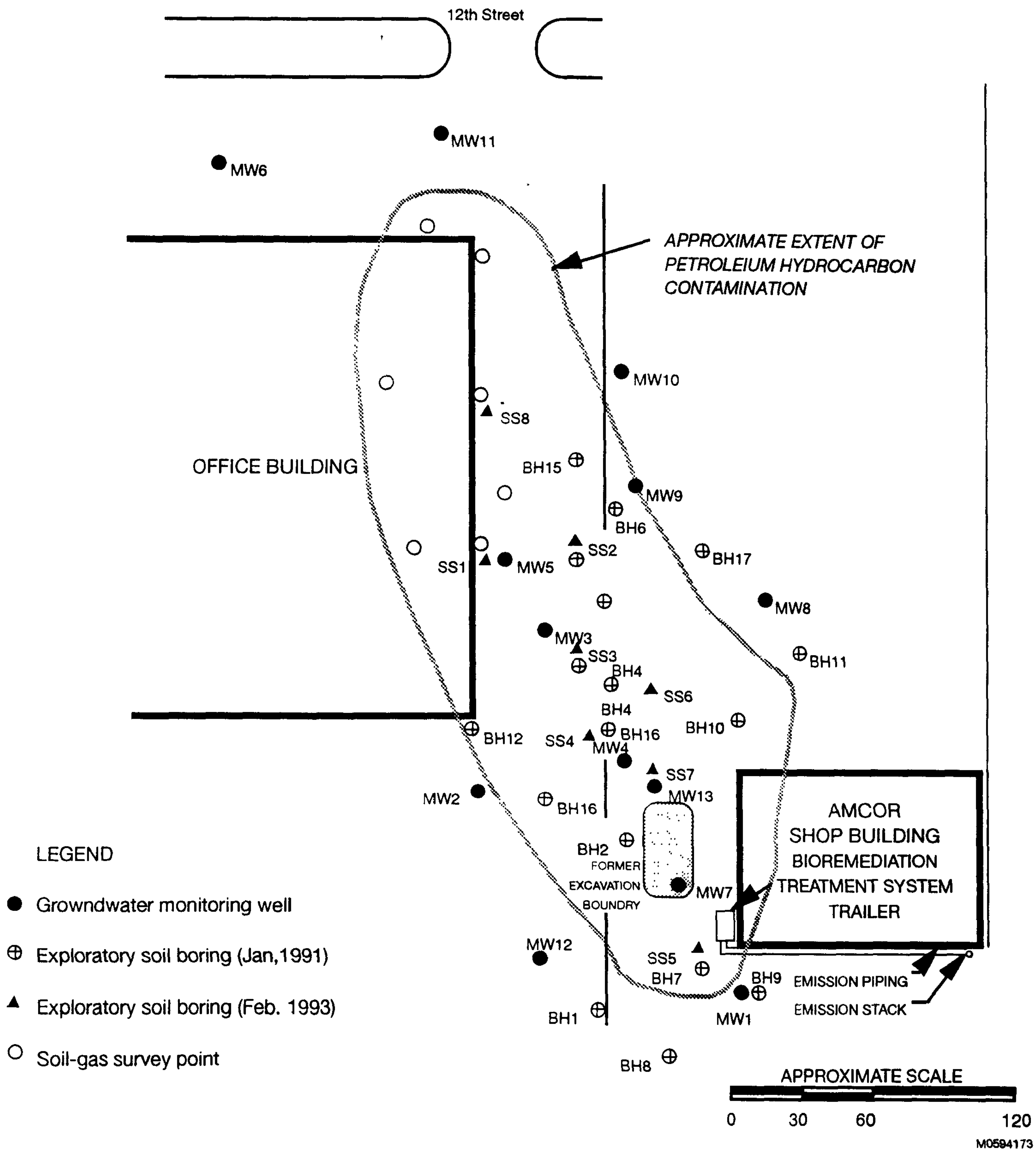

FIGURE 1. SAMPLING LOCATIONS AND PLUME EXTENT, AMCOR PRECAST

Contaminant Locations and Geologic Profiles

The distribution of dissolved groundwater contamination is presented in Figure 1. Contaminants were concentrated within a vertical zone from about 5 to 11 feet below ground surface. The site stratigraphy consisted of interbedded silty sands (SM) and poorly graded fine gravel (GP) underlain by a silty clay (CL) aquitard at a depth of about 18 feet below ground surface.

Site Conditions

- The area has an arid climate with an average ambient temperature of 58°F. The average minimum temperature is 22°F, and the average maximum temperature is 85°F.
- Precipitation averages approximately 20 inches per year, most of which occurs during the winter months.
- The direction of shallow groundwater flow is to the north-northwest.
- The elevation of the site is approximately 4260 feet above mean sea level. The site topography is flat.

Key Soil or Key Aquifer Characteristics

Key soil and groundwater parameters are presented in Table 3.

TABLE 3: KEY SOIL AND GROUNDWATER PARAMETERS

Parameter	Units	Range or Value	Comments
Soil Parameters (Prior to System Startup)			
Porosity	%	20 to 35	Estimated
Particle Density	g/cm^3	2.6 to 2.7	Estimated
Soil Bulk Density	g/cm^3	1.7 to 2.1	Estimated
Aquifer Thickness	ft	7 to 13	
Hydraulic Conductivity	ft/day	190	
Total Heterotrophic Bacteria	cfu/gm	9,300 to 3,000,000	
Total Hydrocarbon Degrading Bacteria	cfu/gm	<100 to 53,000	
Growndwater Parameters (Prior to System Startup)			
Depth to Groundwater	ft	5 to 11	Highest water table in July lowest in January
Dissolved Oxygen	mg/l	0.03 to 1.7	Background
Biological Oxygen Demand	mg/l	5.8 to 90	Proportional to contaminant level
Chemical Oxygen Demand	mg/l	9 to 300	Proportional to contaminant level
NO_3	mg/l	<0.001	
Total PO_4	mg/l	0.18 to 1.3	
TKN	mg/l	0.52 to 1.9	
TDS	mg/l	660 to 700	
Total Heterotrophic Bacteria	cfu/ml	750 to 37,000	
Total Hydrocarbon Degrading Bacteria	cfu/ml	<100 to 7,500	

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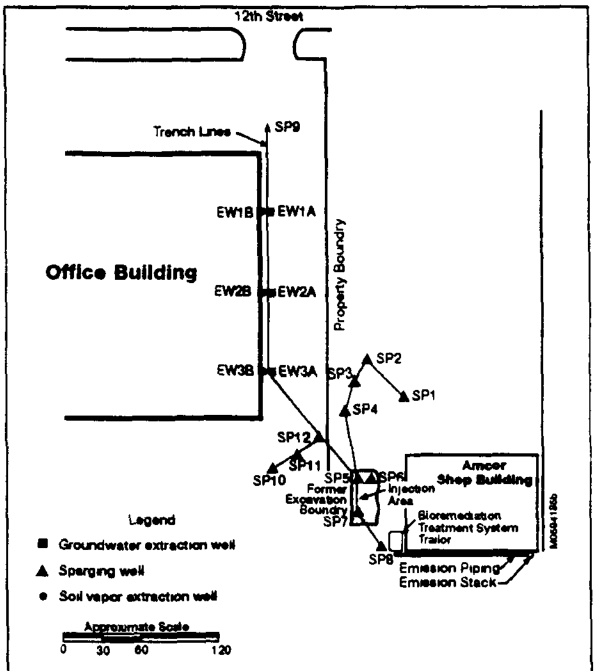
TREATMENT SYSTEM

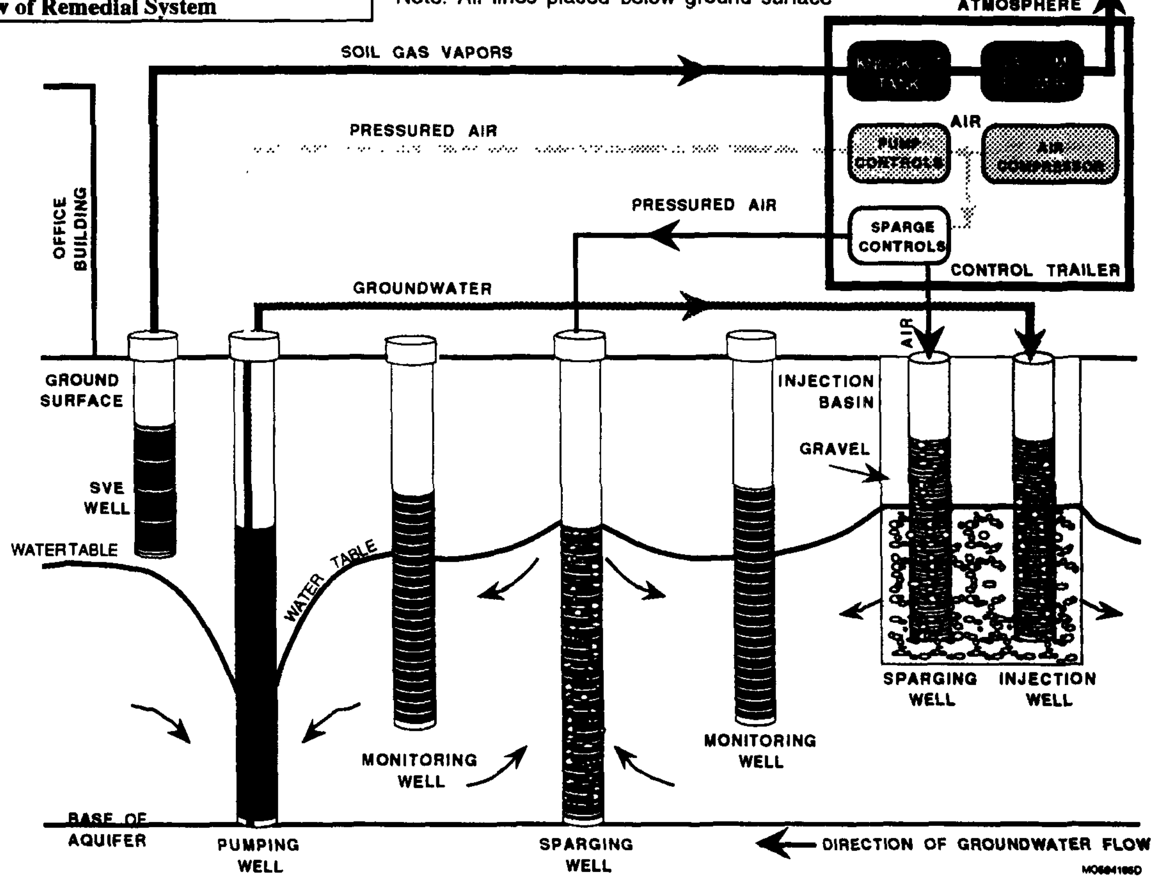
The overall process schematic, as well as a plan view of the remedial system is presented in Figure 2 below.

Figure 2. Plan View and Process Schematic Amcor Precast



Plan View of Remedial System

Note: All lines placed below ground surface



Process Schematic

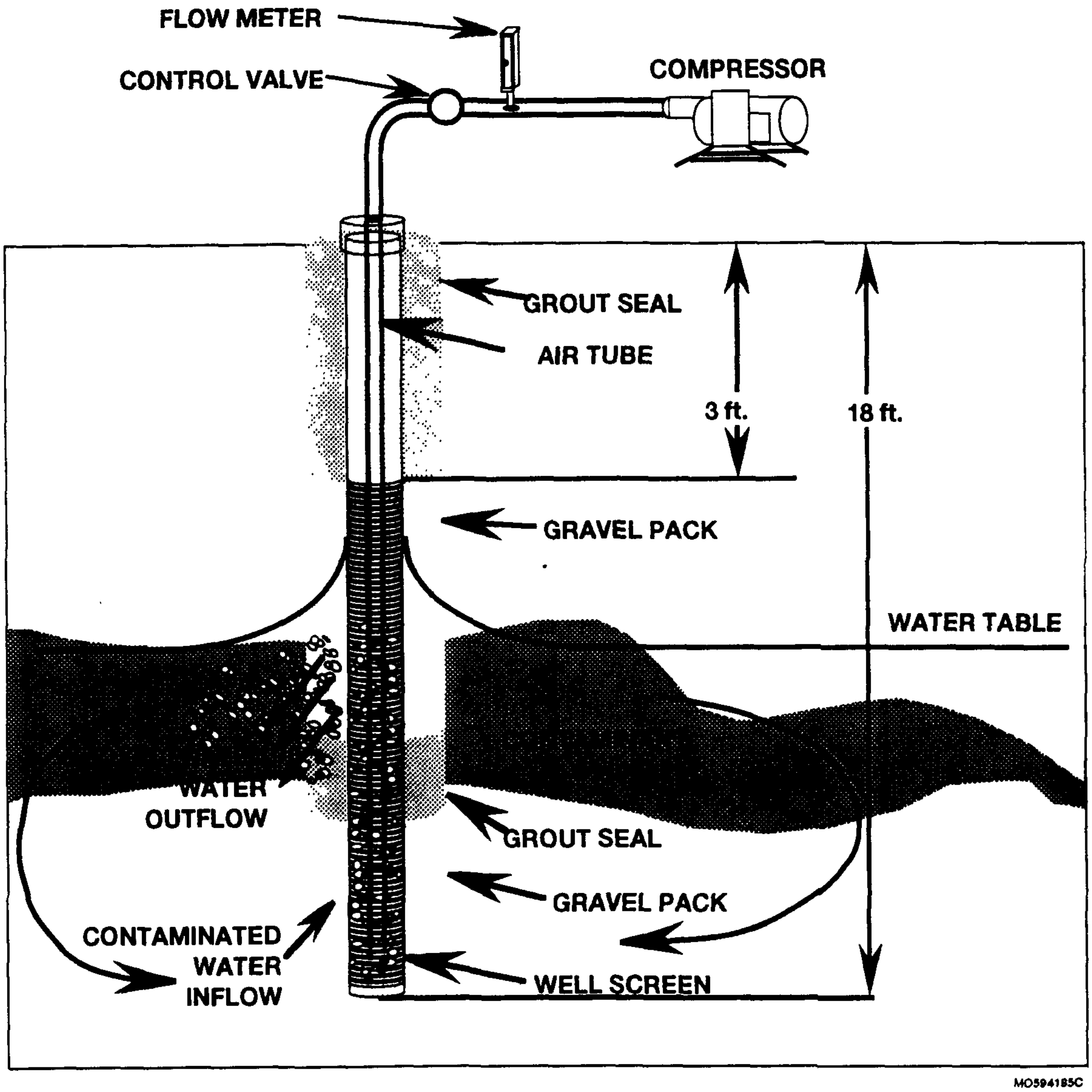


FIGURE 3. DIAGRAM OF DENSITY DRIVEN SPARGING WELL CONSTRUCTION

System Description

The system consists of three principal components: 1) a groundwater sparging system; 2) a groundwater recirculation (pumping) system; and 3) a soil vapor extraction system

- In general, groundwater sparging was the principal method of groundwater remediation employed.
- The density-driven convection system (patent pending) does not attempt to inject air into the soil pore space under pressure like a conventional air sparging system, thereby avoiding the disadvantages of pressurized injection. Instead, water inside the wellbore is aerated directly by injecting air at the base of the wellbore. As show in Figure 3 a grout seal prevents the air from escaping immediately into the formation. The injection air bubbles rise upward in the wellbore, creating a turbulent frothing action. The rising air bubbles airstrip contaminants from the water and increase dissolved oxygen content of the water (to about 10 mg/l). The aeration process also acts as a groundwater pump, pushing aerated water upward through the wellbore and out the upper well screen and drawing resident groundwater from the surrounding aquifer into the base of the well screen thus creating groundwater circulation and transport. The result is a simple small-diameter installation that is virtually maintenance free.

- Density-driven groundwater sparging removes petroleum hydrocarbons from the subsurface by two methods: aerobic biodegradation and *in situ* air stripping.
- The technology promotes aerobic biodegradation by supplying oxygen to the saturated zone via circulation of oxygenated groundwater and to the unsaturated zone via circulation of air.
- The technology promotes *in situ* air stripping by transferring dissolved contaminants from groundwater circulated through the wellbore to air bubbled upwards within the wellbore. Air stripped vapors are transferred to the vadose zone where they are biodegraded in place.
- Soil vapor extraction was used locally to protect against volatilized hydrocarbons created by the air stripping process from entering neighboring office buildings.
- Groundwater was extracted along the downgradient plume boundary and reinjected upgradient (without surface treatment) to prevent further downgradient migration of hydrocarbons below neighboring office buildings.
- The groundwater sparging system consisted of twelve groundwater sparging wells (labeled SP in Figure 2) installed to a depth of 18 feet and connected to a pressurized air supply source via underground lines. Each well was provided with a separate air injection line with flow control and meter at the air supply source.
- The groundwater recirculation system consisted of three downgradient groundwater extraction or pumping wells (labeled EWA in figure 3) installed to a depth of 20 feet and one upgradient injection gallery (former tank excavation backfilled with pea-gravel). Pressurized air supply lines for powering the extraction pumps and water lines for conducting pump discharge to the injection gallery were placed below ground. Pump controls were located at the air supply source.
- The soil vapor extraction system consisted of three vertical vapor extraction wells (labeled EWB in Figure 2) located adjacent to the downgradient pumping wells. The vapor extraction wells are connected to a knock-out tank and regenerative vacuum blower motor via underground lines. Vapors were discharged to the atmosphere via a 35-foot high emissions stack
- Pressurized air for the sparging wells and extraction pumps was supplied by a 36 cfm air compressor. The compressor, vacuum blower for vapor extraction, and associated controls were placed in a portable trailer at the site.

System Operation

- Pressurized air was introduced into the base of each sparging well via the provided air injection tube. Flow rate was controlled at the air supply source. Injected air served to create the driving force for groundwater circulation through the well; increase dissolved oxygen content of water circulated through the well to promote biodegradation in the saturated zone; transfer volatile constituents dissolved in the groundwater to the vadose zone soil gas; and provide oxygen to the vadose zone to promote biodegradation in the vadose zone.
- Pressurized air was also supplied via underground lines to operate the pneumatic groundwater extraction pumps. Extracted groundwater was delivered to the injection gallery without surface treatment. Downgradient extraction was used to prevent further downgradient migration of dissolved hydrocarbons beneath the adjacent office building.
- A vacuum draw was applied to the vapor extraction wells via underground lines attached to a vacuum blower motor. The withdrawn vapor mass was sufficiently low that direct discharge to the atmosphere was allowed. Removal of vapors from the downgradient extraction wells was used to prevent potential migration of product vapors into the neighboring office building. Detectable emissions of petroleum hydrocarbons were not measured after 60 days of system operation.

Closeup of Sparging Well Construction

The sparging well construction is shown in Figure 3 . Each sparging well was installed to a depth of 18 feet below ground surface and screened from 3 to 18 feet. The well casing consisted of schedule 40 PVC flush-coupled well casing and 0.02-inch slotted screen. Air was injected at the base of the well via 3/8-inch diameter plastic tubing.

Key Design Criteria

The key design criteria were as follows:

- Presence of site structures including an office building owned by the neighboring land owner requiring an *in situ* remediation strategy with minimal disturbance to site occupants.
- Elimination of potential product vapor migration into neighboring office building during system operation.
- Control of further downgradient migration of dissolved hydrocarbon plume beneath adjacent office building.
- Sensitivity of neighboring land owner to potential office tenant loss.
- Cost minimization for remedial system installation and operation.

Key Monitored Operating Parameters

System monitoring consisted of the following:

- Collection of air samples from the venting emissions stack and laboratory analysis for Total Petroleum Hydrocarbons (TPH) and Benzene, Toluene, Ethylbenzene, Xylene, and Naphthalene (BTEXN).
- Collection and field analysis of soil gas samples from the vadose zone (plume area and background) for carbon dioxide and oxygen.
- Measurement of field parameters for each monitoring well including water elevation, temperature and dissolved oxygen.
- Collection of groundwater samples from selected monitoring wells and laboratory analysis for TPH and BTEXN.

Monitoring was performed on a weekly basis for the first two months of system operation and monthly thereafter. Confirmatory soil sampling was conducted after eleven months of system operation to evaluate residual soil concentrations.

PERFORMANCE

Performance Objectives

- Reduce TPH and BTEXN concentrations in the site soils to below RCLs established by the Utah Department of Environmental Quality (shown in Table 4). Soil cleanup goals were based on Division of Environmental Response and Remediation recommended cleanup levels (RCLs) with a Level I (most sensitive) environmental sensitivity.
- Reduce TPH and BTEXN concentrations in the site groundwater to below federal MCLs (shown in Table 4). Adopted from the Clean Water Act. No cleanup goals exist for TPH.
- Maintain control over vapor and dissolved phase petroleum product migration.

Treatment Plan

- Maintain groundwater sparging system operation to provide oxygen to promote aerobic biodegradation of petroleum hydrocarbons.
- Maintain downgradient groundwater extraction to prevent further downgradient migration of dissolved petroleum hydrocarbons.
- Maintain downgradient vapor extraction to prevent potential product vapor migration into neighboring office building.
- Evaluate effectiveness of biodegradation by monitoring changes in dissolved hydrocarbon contaminants and bacterial activity. This activity was indicated by dissolved oxygen contents, vadose zone soil gas carbon dioxide and oxygen contents, and bacterial plate counts in groundwater.
- Evaluate effectiveness of plume containment by monitoring downgradient concentrations of dissolved petroleum hydrocarbons.
- Evaluate effectiveness of vapor migration containment by monitoring vapor extraction system emissions and petroleum vapor concentrations in neighboring office building.
- Monitor vapor emissions during system operation to verify compliance with de minimus air emissions standards established by the Utah Division of Air Quality.

Operational Performance

- Concentrations of all of the contaminants of concern were monitored in groundwater and soil to evaluate system performance.
- The following operational performance criteria were maintained during system operation:
  - Sparging well air injection rates maintained at between 60 and 100 scfh.
  - Total groundwater extraction rate (combined flow from all three extraction wells) at 10 gpm .
  - Total soil vapor extraction rate at 70 to 90 scfm.

Cumulative flow was not measured or calculated for system operation.

System inspections and maintenance were conducted at weekly intervals during system operation. The Remediation Conductor estimates that the air compressor used for sparging well and pump operation was operational over 90 percent of the system operational life. He also estimates that the vacuum blower used for vapor extraction was operational over 95 percent of the system operational life.

System downtime was attributed to the following factors:

- Two mechanical compressor failures resulting in two downtime periods of approximately of one week. A pressure modulator was subsequently installed to prevent compressor cycling to reduce compressor wear and to maintain a more constant pressure supply.
- One pneumatic pump control repair (level controls and filter replacement) resulting in downtime of approximately one week.
- Two infiltration basin overflows (three and twelve months after system startup) due to biomass buildup within the injection gallery backfill resulting in downtime of 2 to 3 days for each event.
- Several water knockout tank overfills triggering automated shut-off of the venting system, resulting in downtime of 2 to 3 days for each event.

TREATMENT PERFORMANCE

Vadose Zone Monitoring

- Measured carbon dioxide and oxygen concentrations within the vadose zone remained relatively constant thoughout the first 100 to 150 days of operation, but declined to background levels about 250 days after startup (Figure 5). These data indicate that biological activity was present within the vadose zone through 250 days of operation.
- Measured air emissions from the soil venting system declined rapidly during the initial 60 days following system start-up (Figure 6). These data indicate that physical removal of contamination through vapor extraction was not a primary mechanism in the remedial system operation.

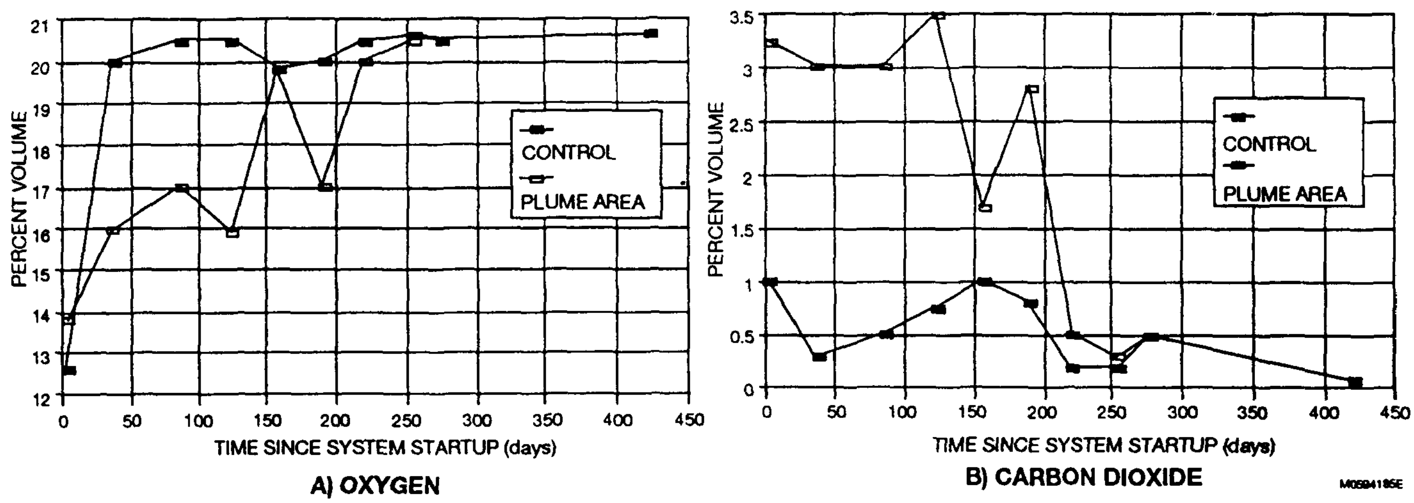


FIGURE 5. OXYGEN AND CARBON DIOXIDE SOIL GAS CONCENTRATIONS

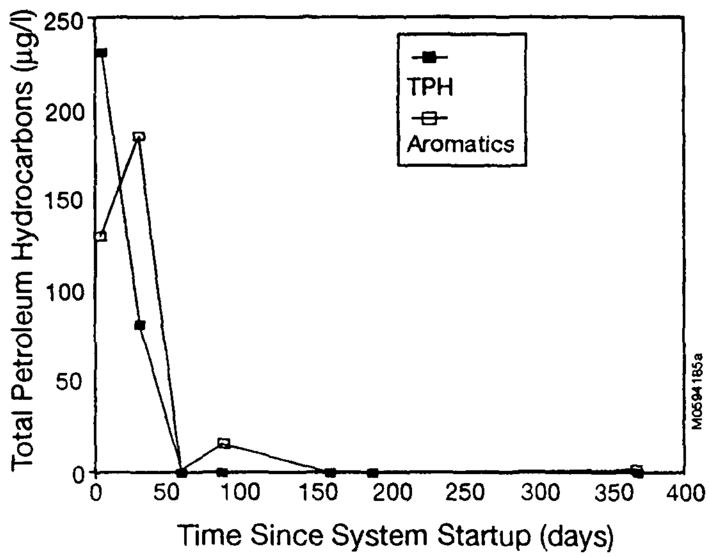


Figure 6. Emissions from Vapor Extraction System

Groundwater Monitoring

- Measurements of dissolved oxygen indicate that concentrations were generally above background levels within the immediate plume area due to the introduction of oxygen by groundwater sparging (Figure 7). These data indicate that although dissolved oxygen initially peaked about 25 days following system startup, subsequent dissolved oxygen concentrations fluctuated between 0.2 and 1.0 ppm through 280 days of operation. Dissolved oxygen was significantly higher during the remainder of system operation, presumably as a result of significant decreases in site contamination.

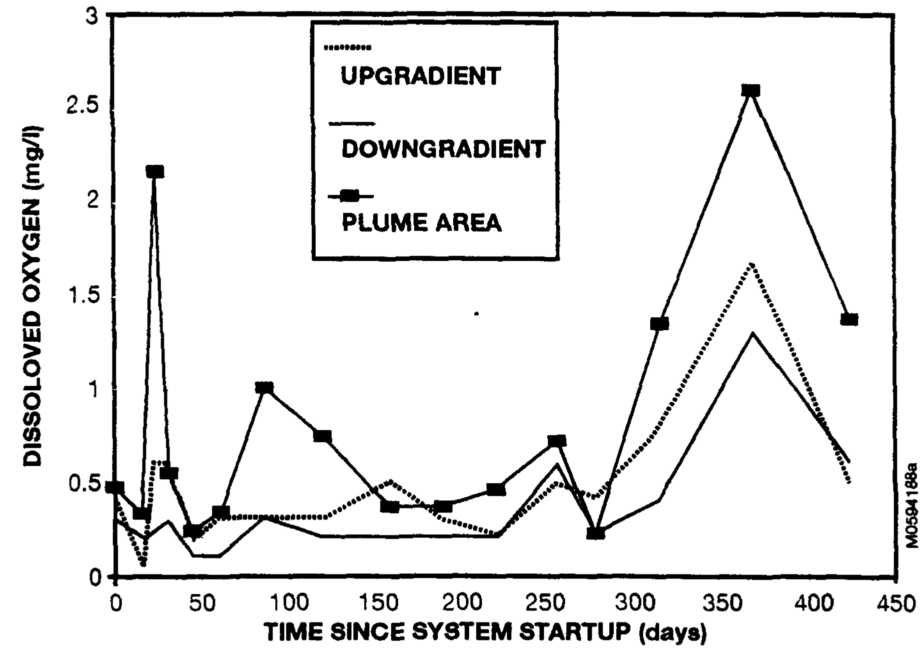


Figure 7. Oxygen Concentration in Groundwater

- Measurements of bacterial plate counts (both total heterotrophic and hydrocarbon degrading) initially increased substantially, but subsequently declined through the first 280 days of operation. These data indicate that bacterial activity was increased within the saturated zone by the groundwater sparging system operation.
- Measurements of dissolved total and aromatic hydrocarbon concentrations in groundwater show long-term declines over the life of the operating system (Figure 9). Dissolved concentrations generally exhibited the following pattern:
  - Concentrations increased over the first 30 days of operation.
  - Concentrations declined dramatically between about 30 and 100 days of operation.
  - Concentrations increased, either slightly or strongly, between about 120 and 250 days of operation.

  Concentrations generally decreased steadily after 250 days of operation.

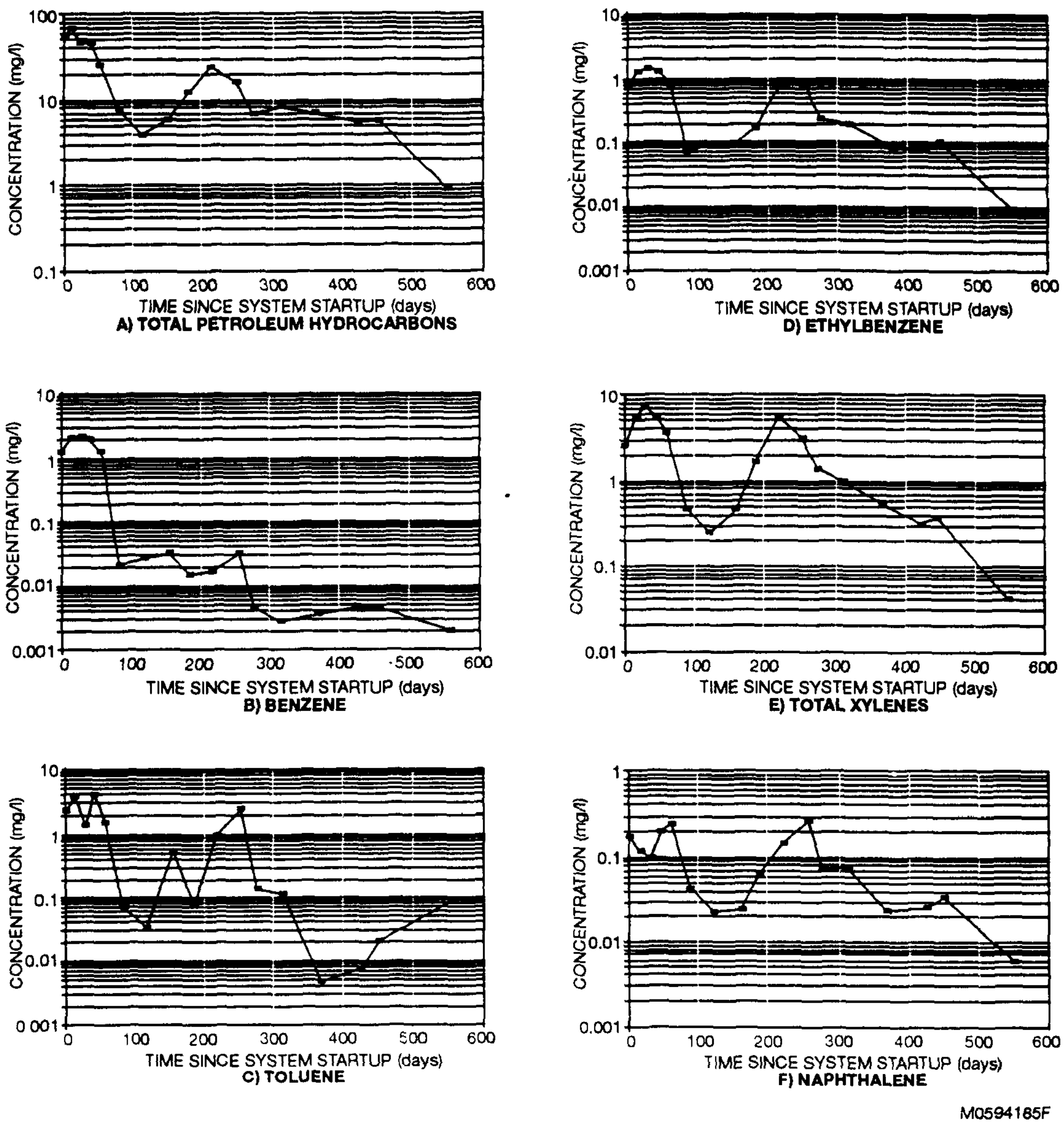


Figure 9. Petroleum Hydrocarbon Concentrations in Groundwater

- The increase in dissolved hydrocarbon concentrations over the first 30 days is probably due to disturbance of the subsurface equilibrium conditions caused by the sparging and pumping operations. Concentrations subsequently declined as microbial activity and associated biodegradation rates increased.
- The cause of the increase in dissolved hydrocarbon concentrations between 120 and 250 days of operation could be the result of any combination of the following factors: increased desorption of hydrocarbons from the site soils due to biological surfactant production and/or seasonal increase in the water table elevation; decreased microbial activity due to a seasonal drop in groundwater temperature or increased competition from non-hydrocarbon degrading bacteria.

Post Remedial Testing

Concentrations of the identified contaminants of concern in soil and groundwater at the completion of the remedial system operation are presented in Table 4. Significant reductions (typically greater than 95%) were observed for all contaminants of concern and both soil and groundwater concentrations were below the regulatory cleanup goals. Soil concentrations were measured 11 months after system startup. System operation and groundwater monitoring was continued for an additional 7 months to achieve compliance with naphthalene MCLs in all wells.

TABLE 4: SUMMARY OF POST REMEDIATION CONTAMINANT CONCENTRATIONS

Contaminant of Concern	Soil Concentrations (mg/kg)			Groundwater Concentrations (mg/l)			Cleanup Goal
	Initial	Final	%Change	Initial	Final	%Change	
Soil Concentrations (mg/kg)							
TPH	1,600	6.3	99.6	555	1.6	99.7	30
Benzene	7.8	<0.1	>98.7	2 0	<0.1	>95.0	0.2
Toluene	2.5	0.4	84.0	1 4	0.1	92.9	100
Ethylbenzene	19	0.1	99.5	5.7	<0.1	>98.2	70
Total Xylenes	110	0.8	99.3	37	0.3	99.2	1000
Naphthalene	No data	<0.1		No data	<0.1		2.0
Groundwater Concentrations (mg/l)							
TPH	190	1 3	99.3	51	0.71	98.6	Not Est.
Benzene	4 7	<0.002	>99.96	1.3	<0.002	>99.8	0.005
Toluene	9 4	0 26	97.2	2.4	0 067	97.2	1 0
Ethylbenzene	2.7	0 021	99.2	0 78	0 007	99.1	0.7
Total Xylenes	8 0	0 063	99.2	2.5	0.063	98.7	10
Naphthalene	0.63	0 010	98.4	0.18	0.006	96.6	0.020

MO594171C

COST

Capital Costs

Drill and Install Wells	$ 16,000
3 extraction	
13 sparging	
6 monitor wells	
Install Groundwater and Vapor Extraction System	$ 40,300
Install Groundwater Sparging System	$ 25,750
Electrical Connections	$ 4,050
Trenching, Soil Disposal, Backfilling, Asphalting	$ 26,800
Air Compressor and Control Trailer	$ 26,800
Initial System Startup and Debugging	$ 3,000
Project Management, Construction Oversight, Regulatory Reporting and Coordination	$ 10,000
TOTAL CAPITAL COST:	**$156,950**

Annual Operating Costs

Maintenance Labor and Parts	$ 30,000
System Monitoring and Reporting	$ 30,000
Electricity (@ $0.07/kW-hr)	$ 2,750
TOTAL ANNUAL OPERATING COST:	**$ 62,750**

REGULATORY/INSTITUTIONAL ISSUES

- The Corrective Action Plan was reviewed and approved by the Utah Department of Environmental Quality (DEQ), Division of Environmental Response and Remediation (DERR).
- The Recommended Cleanup Levels for site soils were derived from DEQ guidelines for Level I environmental sensitivity (highest sensitivity). The environmental sensitivity of the site was evaluated according to the DEQ scoring system.
- The Maximum Contaminant Levels for site groundwater were derived from federal Clean Water Act regulations as adopted by the Utah DERR for underground storage tank remediations
- The Utah Division of Air Quality (DAQ) was notified of the intent to discharge volatile petroleum hydrocarbons from the vapor extraction system to the atmosphere at concentrations below *de minimus* standards established by DAQ (3,000 lbs total volatile emissions per year and 2.0 lbs of benzene per day). Because air emissions were below *de minimus* standards no air discharge permit was required.
- The Utah Division of Water Quality (DWQ) was notified of the intent to discharge contaminated groundwater to the upgradient injection gallery. An authorization-by-rule to operate the injection gallery as a Class V injection well was granted upon demonstration that the injection gallery was within the zone of influence of the downgradient extraction wells.
- Target cleanup levels (RCLs and MCLs) are presented in Table 4.

SCHEDULE

Task	Start Date	End Date	Duration
Tank Removal	12/90	12/90	1 week
Site Investigation	12/91	05/91	6 months
Remedial Investigation	06/91	08/91	3 months
CAP Preparation	09/91	10/91	2 months
CAP Approval by DERR	11/91	11/91	1 month
System Installation	01/92	02/92	2 months
System Operation	03/92	09/93	18 months

LESSONS LEARNED

Key Operating Parameters

- Stimulation of biodegradation was successful by increasing oxygen supply alone. Nutrient addition was not required at this site becouse nitrogen and phosphorous were present in the site groundwater.
- Significant air emissions associated with volatilization of contaminants by vapor extraction and air sparging was limited to the first 60 days of operation, despite the generally volatile nature of the contaminants (gasoline petroleum hydrocarbons). This is probably attributable to promotion of in situ biodegradation in both the saturated and vadose zones. Biodegradation appears to be the predominant mechanism for contaminant removal.
- Measurements of oxygen (soil gas and dissolved), carbon dioxide (soil gas), and bacterial plate counts (groundwater) all proved to be reliable and consistent indicators of biological activity and time required to reach cleanup goals. Dissolved naphthalene was an exception to these operating parameters.
- Groundwater concentrations of dissolved contaminants exhibited significant temporal fluctuations and were less reliable indicators of remedial progress than bioremediation parameters.

Implementation Considerations

- Discharge of air stripped volatile contaminants combined with moisture saturated air flow to the vadose zone permitted *in situ* biodegradation of these contaminants, greatly reducing air emissions from the vapor extraction collection points.
- Sparging wells were located at the point of groundwater reinjection and along a line of wells across the direction of groundwater flow, enhanced by the groundwater recirculation. An alternative strategy in the absence of groundwater recirculation is to space the sparging wells evenly across the entire plume area.

Technology Limitations

- Air sparging is limited to contaminants that can be degraded by indigenous bacteria under aerobic conditions. Length of system operation will be dependent upon the volatility and/or biodegradability of contaminants present. Contaminants which are sufficiently volatile to be air stripped by air sparging but are not aerobically biodegradable (chlorinated solvents for example) may be treatable by this technology with some modifications for vapor collection and treatment.
- The cost to implement air sparging is dependent upon the depth to groundwater since multiple sparging wells are required and their installation costs increases with depth.
- Maximum sparging well air flow and groundwater wellbore circulation rates are dependent upon well diameter, depth to groundwater, and formation hydraulic conductivity. Longer remediation times or a greater number of sparging wells may be required in lower permeability formations.

Future Technology Selection Considerations

- Groundwater circulation and vapor extraction were utilized for groundwater plume and product vapor containment respectively and would not generally be required as an addition to the groundwater sparging system. Subsequent groundwater sparging remediations are being successfully implemented without these additions.
- Air compressors require more maintenance and greater power draw than alternative methods of supplying air for groundwater sparging. Subsequent projects have utilized these alternative and more cost effective methods of air delivery.
- The system was able to reduce contaminant concentrations below required cleanup levels including federal MCLs and Utah RCLs. With the exception of dissolved naphthalene, all cleanup goals were achieved within 12 months of operation, the expected operational life. Reduction of dissolved naphthalene concentrations below the federal MCL of 0.020 mg/l required an additional 6 months of system operation, although the maximum dissolved naphthalene concentrations were only 0.080 mg/l after 12 months of operation. This difficulty probably is attributable to the low volatility and resistance to biodegradation of naphthalene .

SOURCES

Major Sources for Each Section

Site Characteristics:	Sections: 1, 2, 3, 4, 5, 6
Treatment System:	Sections: 7, 11
Performance:	Sections: 8, 9, 10, 11
Cost:	Sections: 7
Regulatory/institutional Issues:	Sections: 7, 11
Schedule:	Sections: 6, 7, 8, 9, 10, 11
Lessons Learned:	Sections: 10, 11

Chronological List of Sources

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2. Spangler, M.G. and Handy, R.L. *Soil Engineering.* Intext Educational Publishers, New York, 1973. pg.166.
3. Montgomery, John. H. and Welkom, Linda M. *Groundwater Chemicals Desk Reference.* Lewis Publishers, Chelsea, Michigan, 1990. pp. 30-31, 308-309, 398-400, 501-502, 547557.
4. Utah Division of Environmental Response and Remediation. *Estimating Numeric Cleanup Levels for Petroleum-Contaminated Soil at Underground Storage Tank Release Sites.* 1990.
5. Industrial Health Incorporated. *Site Investigation,* Amcor Precast, April 17, 1991.
6. Wasatch Environmental, Inc. *Further Site Investigation,* Release Site AGJX, Amcor Precast fueling Area. September 20, 1991.
7. Wasatch Environmental, Inc. *Amended Corrective Action Plan Proposal UST Release Site AGJX Amcor Precast.* October 10, 1991.
8. Wasatch Environmental, Inc. *Quarterly Monitoring Report,* Amcor Precast Fueling Area, UST Release Site AGJX. June 14, 1993.
9. Wasatch Environmental, Inc. *Results and Recommendations for Permanent Closure,* UST Release Site AGJX. November 30, 1993.
10. Schrauf, T.W., Sheehan, P.J., and Pennington, L.H. "Alternative Method of Groundwater Sparging for Petroleum Hydrocarbon Remediation". *Remediation,* Vol 4, No. 3. Winter 1993/1994.
11. Wasatch Environmental, Inc. Project and master files for Amcor Precast, Project No. 1106-1 , -1 A, -1 B, -1 C. Unpublished.

Key Personnel/Point of Contact

Mr. Todd W. Schrauf
Wasatch Environmental, Inc.
2251 B West California Ave.
Salt Lake City, UT 84104
(801) 972-8400

ANALYSIS PREPARATION

This analysis was prepared by:
Stone & Webster Environmental Technology & Service
P.O. Box 5406
Denver, Colorado 80217-5406
Contact: Dr. Richard Carmichael 303-741-7169

REVIEW

Project Manager

The project manager has reviewed this report but he has postponed signing it until final closure of the site has been accomplished.

Regulatory Agency

This analysis accurately reflects the performance of this remediation:

Shelley Quick - DERR x
Environmental Scientist
Utah DERR

Petroleum Product Recovery and Contaminated Groundwater Remediation Amoco Petroleum Pipeline Constantine, Michigan (Interim Report)

Case Study Abstract

Petroleum Product Recovery and Contaminated Groundwater Remediation, Amoco Petroleum Pipeline Constantine, Michigan

<table>
<tr>
<td>Site Name:
Amoco Petroleum Pipeline</td>
<td rowspan="2">Contaminants:
Benzene, Toluene, Ethylbenzene, Xylenes (BTEX), Methyl tert butyl ether (MTBE)
- An estimated 300,000 to 2 million gallons of gasoline, fuel oil, and kerosene released to subsurface
- Free product present in an approximate 6-acre area at an average apparent thickness of 2 feet</td>
<td>Period of Operation:
Status: Ongoing
Report covers - 10/88 to 6/94</td>
</tr>
<tr>
<td>Location:
Constantine, Michigan</td>
<td>Cleanup Type:
Full-scale cleanup (interim results)</td>
</tr>
<tr>
<td>Vendor:
Residuals Management Technology, Inc.</td>
<td rowspan="3">Technology:
Groundwater Extraction followed by Granular Activated Carbon (GAC); In situ Air Sparging of saturated zone
<u>Groundwater Extraction With GAC</u>
- 4 extraction wells installed in two phases (1988 and 1992); depths up to 28 feet below ground surface (bgs) with extraction rates of 50 and 100 gpm
- Extracted water treated using two GAC vessels in series; recovered free product sent to storage in aboveground tanks
<u>In-situ Air Sparging</u>
- 30 two-inch diameter air sparging wells with 3-foot screens
- Installed to depths of 25-30 feet
- Two 300 scfm blowers</td>
<td>Cleanup Authority:
Other: Voluntary cleanup</td>
</tr>
<tr>
<td>SIC Code:
4612 (crude petroleum piping)</td>
<td rowspan="2">Point of Contact:
Paul Ressmeyer
Remedial Project Manager
Amoco Corporation</td>
</tr>
<tr>
<td>Waste Source:
Other: Petroleum pipeline leak</td>
</tr>
<tr>
<td>Purpose/Significance of Application:
Full-scale pump and treat of petroleum contaminated-groundwater using granular activated carbon to recover free product and treat groundwater. In situ air sparging was subsequently added to treat the saturated zone.</td>
<td colspan="2">Type/Quantity of Media Treated:
Groundwater
- 775 million gallons of groundwater between 1988 and 1993
- Sand and gravel
- Porosity 30-40%
- Hydraulic conductivity 0.0002 - 0.0004 cm/sec</td>
</tr>
<tr>
<td colspan="3">Regulatory Requirements/Cleanup Goals:
- The remediation is being performed as a voluntary action by Amoco; final cleanup criteria will be established in the future with concurrence from the Michigan Department of Natural Resources
- Treated water required to meet SPDES permit requirements prior to discharge - benzene (5 µg/L), total BTEX (20 µg/L), MTBE (380 µg/L), pH (6.5-9.0)</td>
</tr>
</table>

Petroleum Product Recovery and Contaminated Groundwater Remediation, Amoco Petroleum Pipeline Constantine, Michigan (Continued)

Results:

Groundwater Extraction with GAC
- 118,000 gallons of free product recovered (10/87-12/93); rate of free product recovery has decreased to 20 to 25 gallons per month as of late 1993
- Free product has been hydraulically contained and observed apparent thickness of free product has been reduced to <0.01 feet
- Concentrations of BTEX in extracted groundwater have remained relatively constant; MTBE concentrations have decreased
- Treated effluent from GAC have generally met SPDES discharge limits

In-situ Air Sparging
- Pilot testing indicated a radius of influence of 65-150 feet per single well
- No additional results were available at the time of this report

Cost Factors:
- Total Capital Costs: about $297,000 for groundwater recovery and treatment system (including well construction, pumps, system installation, engineering); $375,000 for the air sparging system (including 3 months of initial operations, and testing)
- Annual Operating Costs (approximate): about $475,000 for groundwater recovery and treatment system; not yet defined for air sparging system
- An estimated total cost for completing the cleanup is not available at this time

Description:

The Amoco Corporation owns and operates a liquid petroleum product pipeline that transverses the Constantine site. As a result of a pipeline leak, discovered in June 1987, an estimated 350,000 to 2 million gallons of gasoline, fuel oil, and kerosene were released to the subsurface. Free product was present at an average apparent thickness of 2 feet. Beginning in October 1988, a groundwater pump and treat system, consisting of 4 extraction wells and granular activated carbon (GAC) vessels, was used to recover free product and treat the contaminated groundwater. In situ air sparging of the saturated zone was subsequently added and began operating in February 1994.

Through December 1993, groundwater extraction with GAC had recovered an estimated 118,000 lbs of free product and reduced the observed apparent thickness of the free product layer to <0.01 feet. MTBE concentrations were reduced; however, BTEX concentrations near the source of contamination remained relatively constant. No full-scale performance data were available for the air sparging system at the time of this report.

The groundwater extraction with GAC system operated > 95% of the time through December 1993. Periodic shutdowns of 1 to 3 days were required for carbon changeout and extraction well rehabilitation. Leasing the activated carbon system and carbon provided flexibility to modify the treatment system in response to changing operating conditions. However, GAC proved to be inefficient in removing MTBE when compared to BTEX.

SITE

Amoco Petroleum Pipeline
A Voluntary Cleanup
Constantine, Michigan
(Constantine Site)

TECHNOLOGY APPLICATION

This analysis covers an effort to **hydraulically contain and recover free product as well as pump and treat groundwater** using **granular activated carbon (GAC)** at a site contaminated with **petroleum products.** Recovery and treatment began in 1988 and is ongoing. **In-situ air sparging** was initiated in February 1994 to enhance groundwater restoration.

SITE CHARACTERISTICS

Site History/Release Characteristics

• A liquid petroleum product pipeline owned and operated by Amoco Corporation transverses the Constantine site from northeast to southwest. A leaking gasket associated with a central valve station for the pipeline was discovered in June 1987. Approximately 350,000 to 2 million gallons of gasoline, fuel oil and/or kerosene were released to the subsurface as a result of the leak.

• The leak was immediately repaired. Subsurface investigations to define the nature and extent of free product and groundwater contamination were initiated in July 1987. Manual recovery of free product from monitoring wells was initiated in November 1987.

• An interim free product and ground-water recovery and treatment system commenced operation in October 1988. The interim system was still in operation as of May 1994. In-situ air sparging of the saturated zone began in February 1994.

Contaminants of Concern

Contaminants of Concern used to track the progress of groundwater remediation are:

Benzene
Toluene
Ethylbenzene
Xylenes
} (known as BTEX)
Methyl tert butyl ether (MTBE)

Free petroleum product, the source of the contaminants identified above, was also present.

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Properties*	Units	B	T	E	X	MTBE
Chemical Formula	-	C_6H_6	$C_6H_5CH_3$	$C_6H_5C_2H_5$	$C_6H_4(CH_3)_2$	$C_5H_{12}O$
Specific Gravity	-	0.88	0.87	0.87	0.86-0.88	0.74
Vapor Pressure	mm Hg	95.2	28.1	7	10	245
Water Solubility	mg/l	1,750	535	152	198	48,000
Octanol -Water Partition Coefficient; K_{OW}	-	132	537	1,100	1,830	1.05
Organic Carbon Partition Coefficient; K_{OC}	-	83	300	1,410	240	-

** Properties at 20 °C.*

Nature & Extent of Contamination

• Characterization of the nature and extent of contamination at the Constantine site focused on free petroleum product and petroleum hydrocarbons dissolved in groundwater. The initial characterization (completed in October 1987) indicated free product was present over an approximate 6 acre area in the vicinity of the valve station, at an average apparent thickness of 2 feet.

• Petroleum hydrocarbons dissolved in groundwater were detected in the vicinity of the free product and to the west and southwest (downgradient) in October 1987. In the spring of 1991, quarterly monitoring data indicated that some dissolved BTEX and MTBE had migrated downgradient beyond the influence of the interim recovery well network, and were entering a drainage ditch.

Contaminant Locations and Geologic Profiles

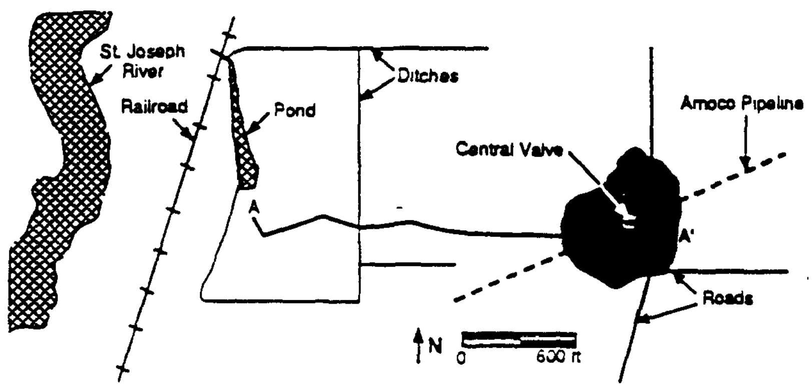
Remedial investigation field activities at the site have included:

- Borings and subsurface sampling
- Monitoring well installation and groundwater sampling
- Groundwater level measurements
- Apparent product thickness measurements
- Hydropunch™ groundwater sampling
- Well permeability and pump testing
- Surface water sampling and water level measurements

Data from some of these efforts have been included here to provide a conceptual understanding of site conditions.

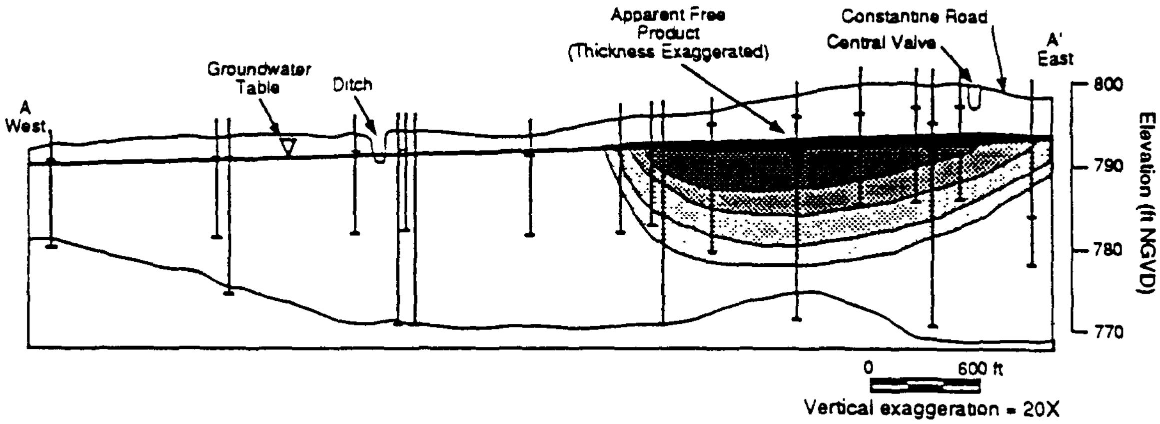
Initial Extent of Free Petroleum Product (Plan View)

Data from October 1987



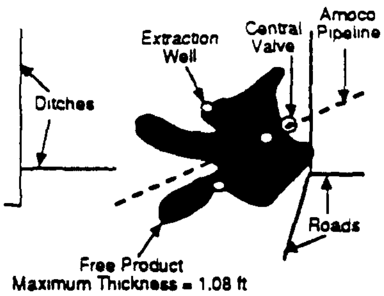
Extent of Free Product and Dissolved BTEX in Groundwater (Cross-Section)

Groundwater monitoring data from 1990 along cross-section A-A' shown in plan view.



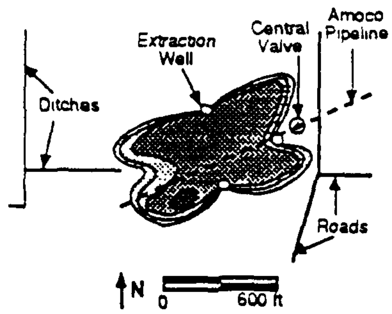
Extent of Free Product (Plan View)

Groundwater monitoring data from1990.



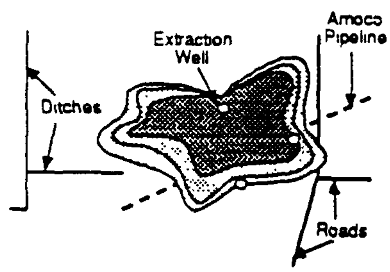
Extent of Dissolved BTEX in Groundwater (Plan View)

Groundwater monitoring data from1990.



Extent of Dissolved MBTE in Groundwater (Plan View)

Groundwater monitoring data from1990.



Legend

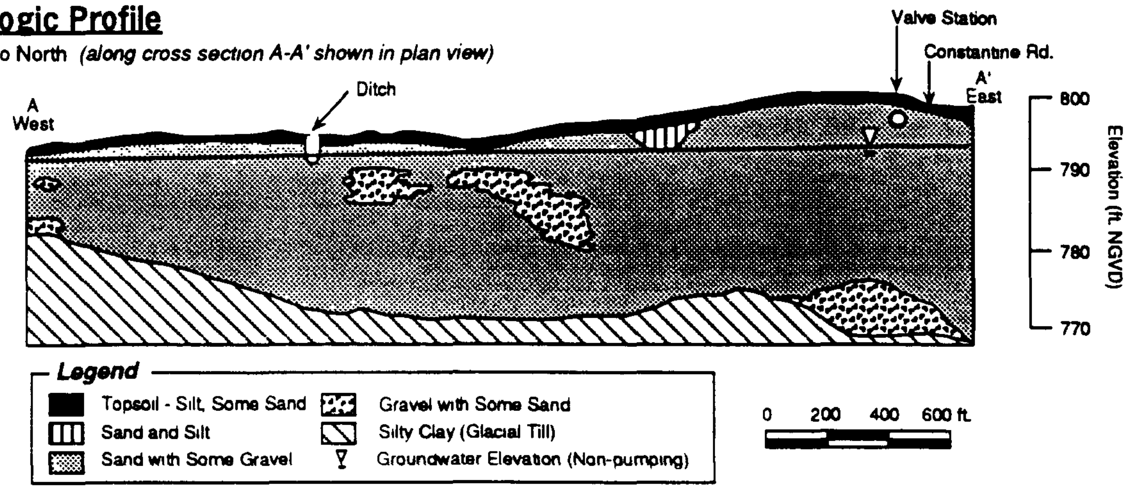
all concentrations in ppb

- 10-100 ppb
- 100-1,000 ppb
- 1,000-10,000 ppb
- >10,000 ppb
- Free Product

Contaminant Locations and Geologic Profiles (Continued)

Geologic Profile

View To North *(along cross section A-A' shown in plan view)*



Site Conditions

- Topography of the Constantine site is relatively flat, ranging from ~ 800 ft. N.G.V.D. near the pipeline's central valve station to ~ 788 ft. N.G.V.D. at the St. Joseph River, located ~ 3,000 ft. west of the central valve station.
- Groundwater flow from the site is generally to the west and southwest, discharging to drainage ditches, a pond, and ultimately the St. Joseph River. The water table in the shallow sand and gravel unit is 2 to 10 ft. below ground surface.
- Site stratigraphy is relatively straight forward. Approximately 10 to 29 ft. of interbedded sand and gravel overlies a silty clay glacial till unit. Cobble-size sediments and sandy silt deposits were also occasionally encountered.

Key Aquifer Characteristics

Aquifer parameters for the shallow sand and gravel unit at the Constantine site have been estimated as:

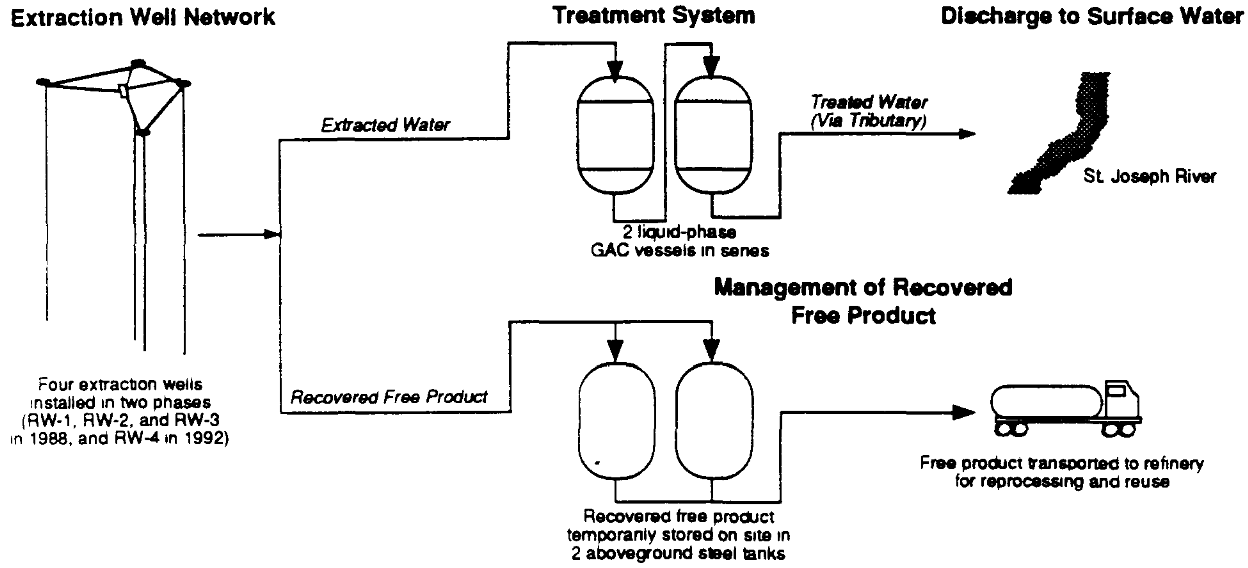
Property	Units	Range
Soil Porosity	%	30 - 40
Particle Density	g/cm^3	2.65 - 2.70
Bulk Density	g/cm^3	1 8 - 2.2
Particle Diameter	mm	0.9 - 4.5
Organic Content	%	0.8
Permeability	cm^2	2E-9 to 4E-9
Hydraulic Conductivity	cm/s	2E-4 to 4E-4
Static Hydraulic Gradient	ft/ft	0.0018
Groundwater Flow Velocity (Avg.)	ft/yr	500
Rainfall Infiltration	cm/day	0.07
Microbial Plate Counts	CFU/g	2.2E4 to 4.1E5

Property	Units	Range
Dissolved O_2 (in plume)	mg/l	0.8
Dissolved O_2 (background)	mg/l	7.8
Total Phosphorous	mg/l	0.029 - 2.15
Nitrate-N	mg/l	3.6 - 13
Nitrite-N	mg/l	0.001 - 0.005
Kjeldahl-N	mg/l	0.28 - 1.1
Ammonia-N	mg/l	<0.02 - 0.08
Calcium	mg/l	30 - 46
Total Alkalinity	mg/l	139 - 154
Hardness (as $CaCO_3$)	mg/l	150 - 450
pH	-	6.96 - 7.08
Iron	mg/l	<0.02 - 0.82
Manganese	mg/l	<0.01
Magnesium	mg/l	5.68 - 10.4

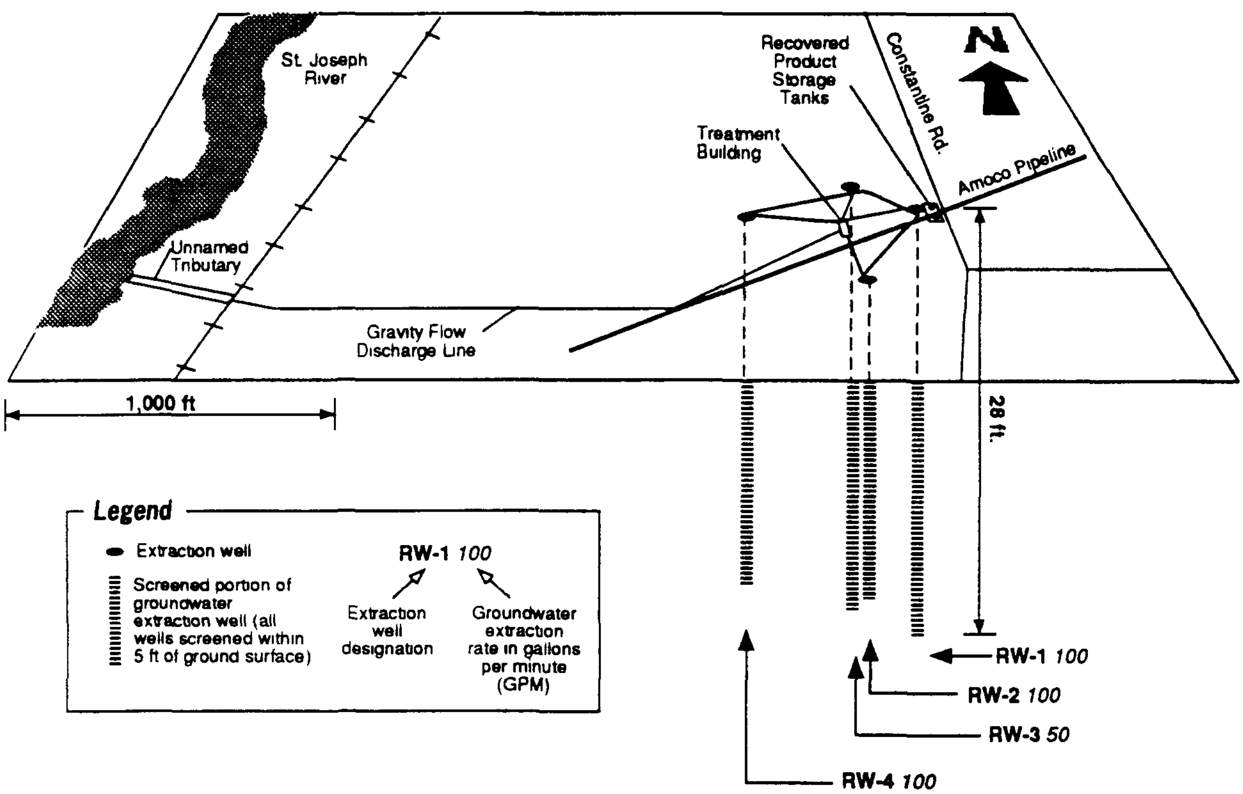
- Unconfined groundwater conditions exist at the Constantine site.
- The presence of a substantial number hydrocarbon-degrading micro-organisms within the dissolved hydrocarbon plume, the difference in dissolved O_2 concentrations in groundwater outside versus within the dissolved hydrocarbon plume, and the sharp decrease in BTEX concentrations at the downgradient edge of the dissolved hydrocarbon plume indicate that natural (intrinsic) bioremediation of the BTEX dissolved in groundwater is occurring.

REMEDIATION SYSTEM

Overall Process Schematic

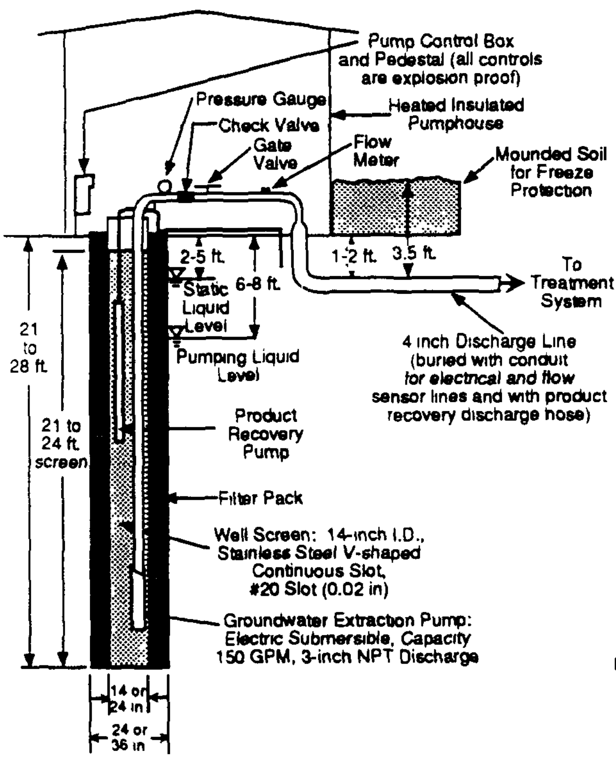


Extraction Well Network



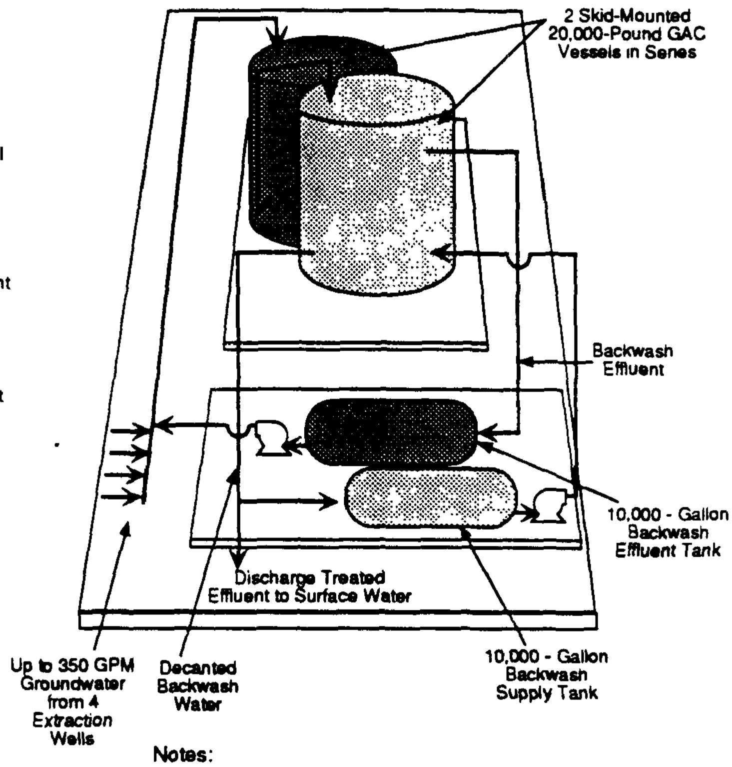
Extraction Well Detail

Typical Extraction Well



Notes: Extraction well RW-4 not equipped with product recovery pump.
All extraction wells developed by surging and pumping.

Treatment System Schematic



Notes:

1) Piping configured to allow use of either carbon vessel as primary absorber and backwashing of both carbon vessels.

2) Free product piped from extraction wells to 2-5,000 gallon storage tanks located remote from treatment system building.

Key Design Criteria

- Hydraulic containment of free product and dissolved-phase contamination.
- Recovery of water and free product using two-pump system to avoid emulsifying water/oil.
- Handle range of flow rates to allow for operational flexibility.
- Maximize efficiency of activated carbon to remove BTEX from extracted groundwater.
- Automated treatment system monitoring and shutdown.

Key Monitored Operating Parameters

- Water flows
- Pump discharge pressures
- Carbon bed pressures
- Automated processes

(to assess system operation)

- Groundwater levels

(to assess capture zone)

- Contaminant concentrations in treatment system influent & effluent

(to assess treatment system effectiveness)

- Apparent free product thickness and contaminant concentrations in groundwater

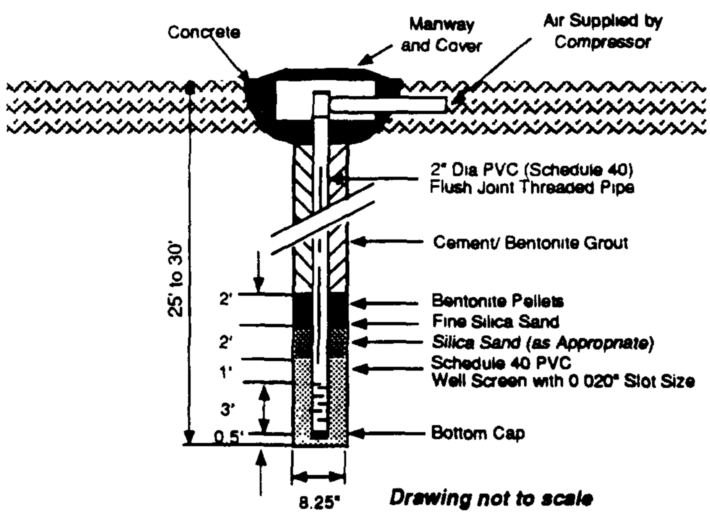
(to assess remediation progress)

In-situ Sparging System

• The in-situ sparging system consists of 30 two-inch diameter air sparging wells within a 3-foot long screened section installed into a depth of approximately 25 to 30 feet, two 300 scfm blowers housed within the groundwater treatment shed, and buried manifold connecting the blowers and sparging wells.

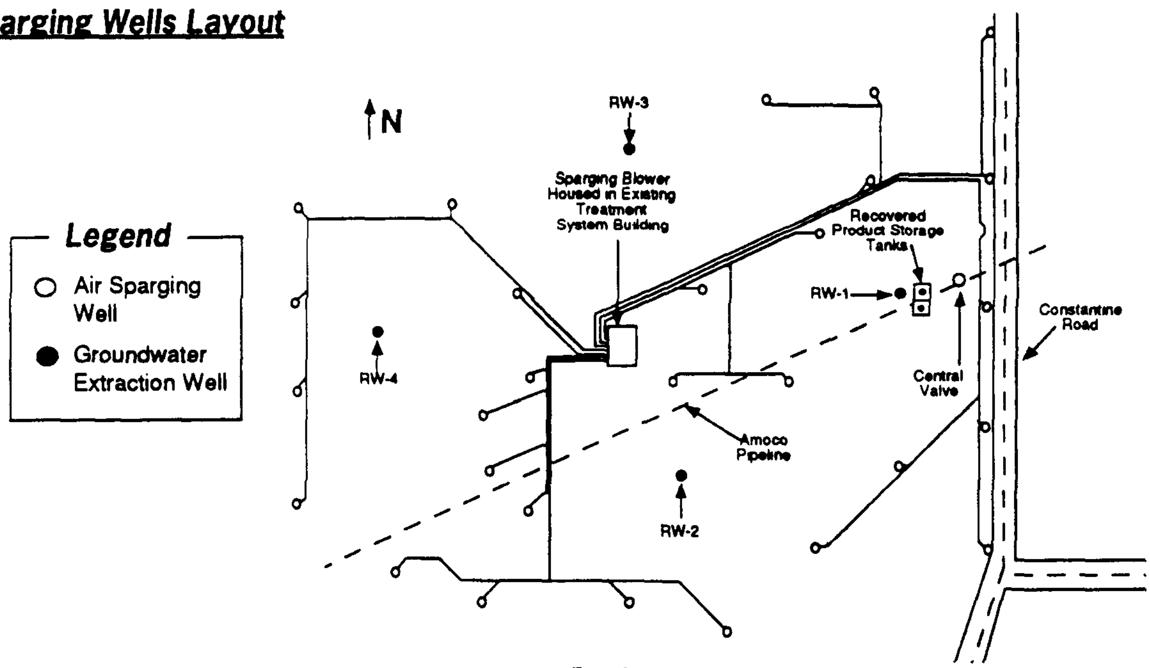
• Sparging will be performed at an air flow rate of between ~10 and 30 scfm and a pressure of 12 pounds per square inch at each well.

Typical Sparging Well



Drawing not to scale

Sparging Wells Layout



Drawing not to scale

PERFORMANCE

Performance Objectives

- Prevent migration of free petroleum product and petroleum constituents dissolved in groundwater.
- Recover free petroleum product.
- Reduce concentrations of petroleum hydrocarbons dissolved in groundwater.

Remedial Action Plan

Remediation at the Constantine site is being implemented in a phased manner:

1987/ 1988 Installation and operation of interim free product and groundwater recovery and treatment system based on results of preliminary investigation.

↓

1988 - 1992 Subsequent extraction and treatment system modifications/enhancements based on comprehensive investigation results.

↓

Initiated 1994 In-situ saturated zone air sparging to enhance natural volatilization and bioremediation.

Overall Performance Summary

Conclusions drawn after 5 (plus) years of operating the interim free product and groundwater recovery and treatment system are summarized below:

- Successful hydraulic containment and substantial recovery of observed free-phase petroleum product was achieved.
- Substantial hydraulic containment of petroleum constituents dissolved in groundwater was achieved near the release source.
- A portion of the dissolved phase contamination migrated beyond the capture zone of 3 extraction wells. A fourth extraction well installed in 1992 was apparently effective in limiting additional migration of dissolved-phase constituents from near the source area.
- The concentration of BTEX in extracted groundwater did not decrease substantially due to continued solubilization of hydrocarbons from free product and residual soil contamination. Substantial decreases of MTBE in extracted groundwater occurred during the same period.
- Concentrations of petroleum constituents in treated effluent have met State Pollution Discharge Elimination System (SPDES) discharge limits with minor exceptions.

Operational Performance

Volume and Rate of Water Pumped

- From Oct. 1988 through Dec. 1993 approximately 800 million gallons of groundwater was pumped from 3 to 4 extraction wells; average daily flows were maintained below the SPDES permit limit of 350 GPM.
- During this period, suspended solids loading on the GAC system limited flow rates to a (project) average rate of approximately 315 GPM.

System Downtime

- The treatment system has operated 95% (plus) of the time between Oct. 1988 through Dec. 1993. Periodic shutdowns of 1 to 3 days occur for carbon changeout and extraction well rehabilitation. Additional downtime was experienced for equipment modification and replacement.
- A 10-day shutdown in early July 1991 was caused by the delivery of contaminated GAC by a carbon vendor.

Volume and Rate of Free Product Recovered

- From Oct. 1987 through Dec. 1993, approximately 118,000 gallons of free product had been recovered.
- The rate of free product recovery plateaued in late 1990. Free product recovery rates had decreased to approximately 20 to 25 gallons per month by late 1993.

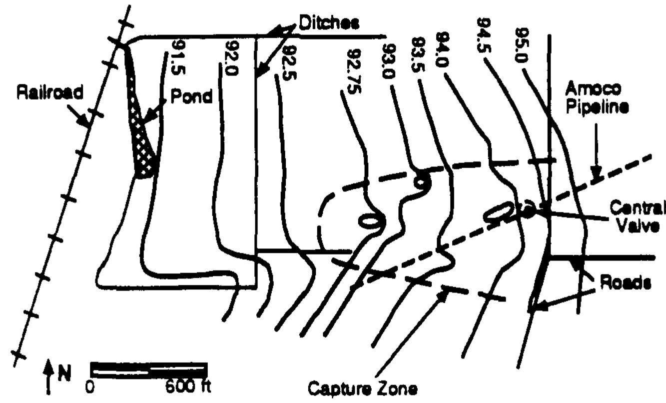
Hydrodynamic Performance

• The capture zone created by the extraction well network provides for substantial hydraulic containment of petroleum constituents dissolved in groundwater.

• The capture zone does not allow for recovery of dissolved petroleum constituents near the surface ditches. This downgradient contamination probably resulted from periodic decreased pumping rates caused by plugging of extraction wells with biomass and oxidized inorganics.

Groundwater Elevations and Zone of Capture

Data from October, 1993.



Remediation System Performance

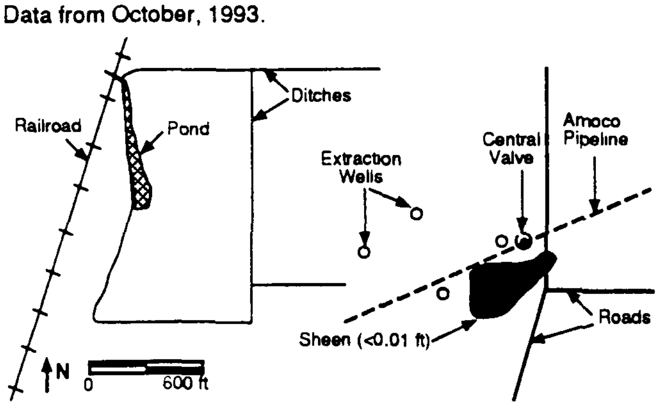
Effect on Free Product

• The recovery system has hydraulically contained free petroleum product and has reduced the observed apparent product thickness to a sheen (<0.01 feet).

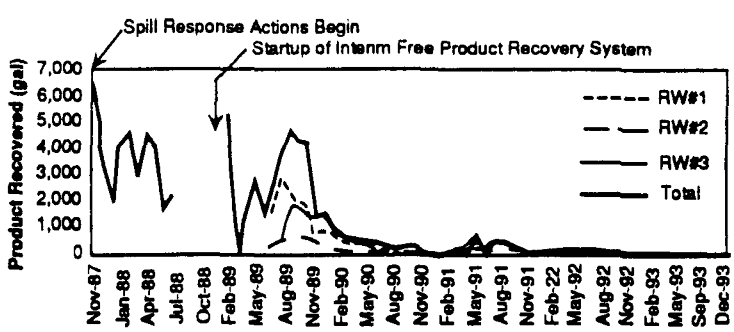
• Product recovery rates plateaued in late 1990. Free product recovery rates had decreased to approximately 20-25 gallons/month by October 1993.

Apparent Free Product Thickness

Data from October, 1993.



Product Recovery Per Month



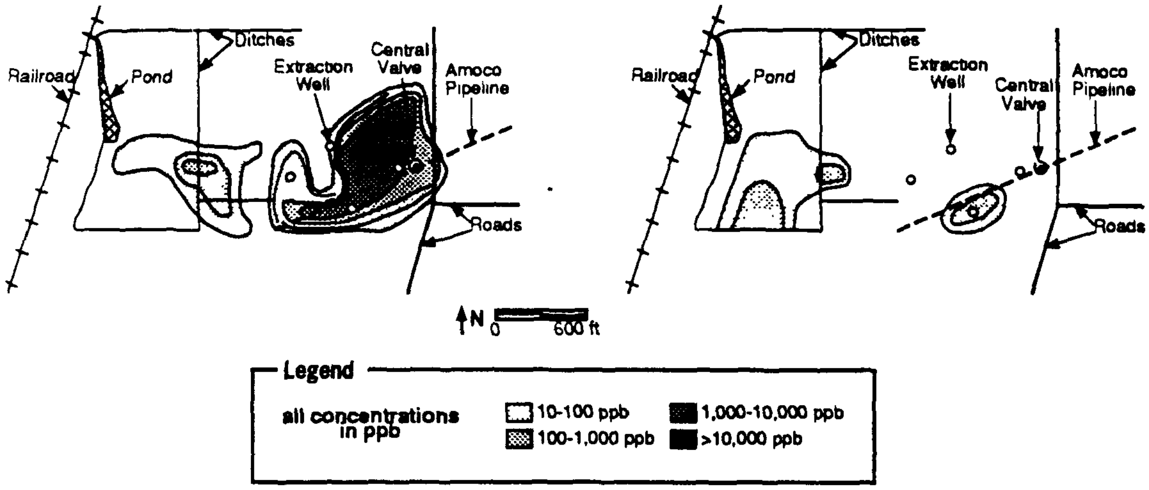
Remediation System Performance (Continued)

Effects on Dissolved Constituents in Groundwater

- Concentrations of BTEX in groundwater within the capture zone have remained relatively constant since initiating remediation. Increasing concentrations of BTEX in groundwater was observed downgradient from the capture zone in 1990.
- Concentrations of MTBE in groundwater decreased more rapidly than BTEX in the capture zone area. MBTE also migrated downgradient of the capture zone more rapidly than BTEX .

BTEX in Groundwater
Data from October, 1993.

MTBE Groundwater
Data from October, 1993.



Treatment Equipment Performance

- The treatment system was modified late in 1991 because of operational limitations caused by suspended solids clogging of bag filters and carbon vessels. Two parallel sets of 10,000 - pound carbon vessels were replaced with one pair of 20,000 - pound carbon vessels (in series). A manual water and air backwash system was also installed to extend carbon life and allow ground-water extraction rates to be maintained. The bag filters were eliminated in late 1992.

- Except for occasional excursions of discharge limits caused by operator error and delivery of contaminated carbon during the initial stages of remediation, the GAC treatment system has achieved a 99% (plus) removal rate for BTEX. Removal efficiencies for MTBE have been highly variable, depending on the frequency of carbon replacement. MTBE influent and effluent concentrations have remained well below the discharge limit since being instituted in 1993.

Sparging Wells Performance

- Pilot testing indicated a radius of influence of 65 to 150 feet for single sparging wells based on measured rise in groundwater levels and initial dissolved oxygen increases in groundwater up to 25 feet from the sparging wells. Close monitoring of the sparging system is planned to determine actual remedial performance and ensure continued hydraulic containment of petroleum hydrocarbons dissolved in groundwater using the existing groundwater extraction system.

COST

• The interim free product and groundwater recovery and treatment system was designed and constructed in 1987-1988. The treatment system was modified and an additional extraction well was put into service in 1992. Leasing of the activated carbon vessels and activated carbon (with purchase option) provided the flexibility to adjust to changing operating conditions, resulting in increased operating efficiency and cost effectiveness. Approximate capital and operating costs are provided below.

• During 1988 - 1993, the average volume of water treated by the interim groundwater pump and treat system was approximately 155 million gallons per year. The total cost of operation and maintenance is ~ **$0.003 per 1,000 gallons treated.**

Capital Costs

Construction of Wells (4 extraction)	$ 32,000
Groundwater and Product Recovery Pumps	30,000
Trenches/Piping and Well Houses	10,000
Treatment System Installation	40,000
Treatment System Controls	10,000
Building, HVAC, Utility Service	*53,000*
Access Road	2,000
Recovered Product Storage Tanks, Diked	20,000
Engineering (excluding site characterization & other studies)	100,000
Total Capital Cost	**~$ 297,000**

Annual Operating Costs

The total annual operation and maintenance cost (excluding laboratory analysis of groundwater samples) is **~$475,000**. This cost includes:

- Carbon System Rental
- Carbon Changeout, Transport & Regeneration
- Electrical Power
- Equipment, Repair and Replacement
- Laboratory Analysis for Influent/Effluent
- Transport of Recovered Product
- O&M Labor
- Engineering Support

An **in-situ sparging system** was installed in late 1993/early 1994 to further reduce the concentration of saturated zone petroleum hydrocarbons. The total capital cost for the sparging system was $375,000, including 3 months of initial operations and testing. Operating costs sparging system have not yet been defined.

Notes: All costs presented are approximate. Costs for Amoco project management are not included.

REGULATORY/INSTITUTIONAL ISSUES

• The Constantine site remediation is being performed as a voluntary action by Amoco. Final cleanup criteria for the site will be established in the future with the concurrence from the Michigan Department of Natural Resources (MDNR).

• The interim product and groundwater recovery and treatment system was designed in 1987 but was not installed until 1988 due to administrative delays in obtaining the SPDES permit.

• Treated water is discharged under the authority of a SPDES permit issued by the MDNR. The initial SPDES permit was issued in 1987 and modified in 1989. The current SPDES permit was issued in in 1993. Discharge limits are summarized below:

	1987/1989 Permit		1993 Permit
Compounds	Monthly Average	Daily Maximum	Monthly Maximum
Benzene	51	-	5
Toluene	100	-	-
Ethylbenzene	62	-	-
Xylenes	40	-	-
Total BTX	-	20	-
Total BTEX	-	-	20
MTBE	-	-	380
pH	-	-	6.5 - 9.0

Note: All units in ug/l (except pH).

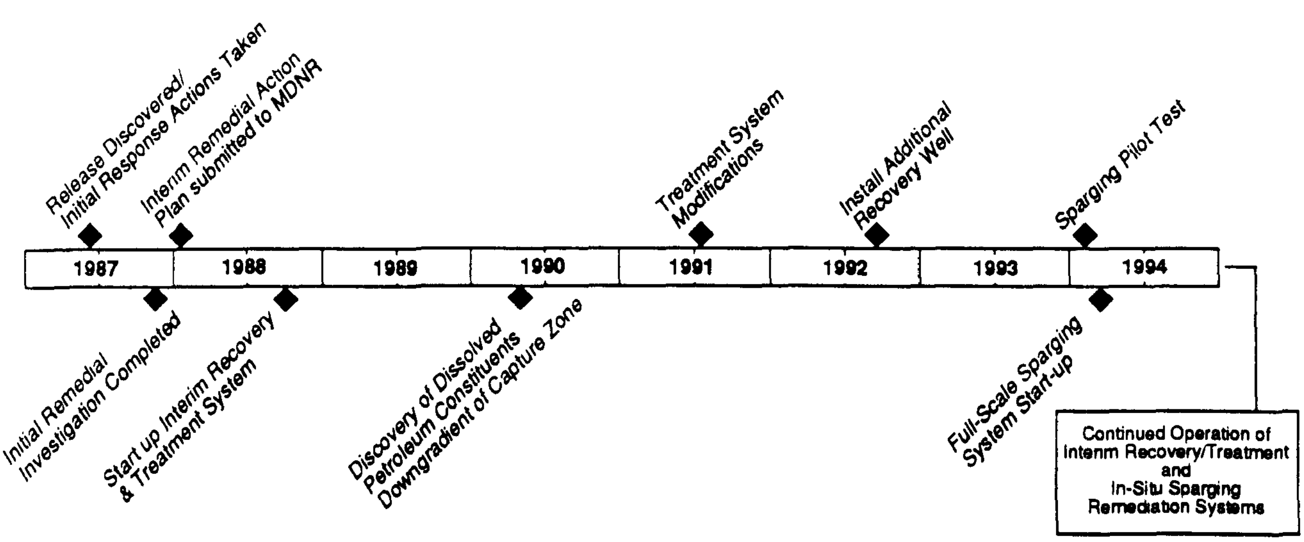
• Air permits were not required by the MDNR for the air sparging system.

• Petroleum constituents in groundwater led to the installation of point-of-use drinking water treatment systems for two residences. A positive pressure ventilation system was installed to prevent petroleum vapors from entering the basement of one of the residences.

• New water supply wells were installed for a nearby farmer. The wells replaced the pond downgradient of the Constantine site as a source for agricultural irrigation water.

SCHEDULE

Major Milestones



LESSONS LEARNED

Implementation Considerations

- An understanding of the extent of contamination at this site evolved over a period of 5 years of investigation, monitoring, and remediation. Defining the extent of contamination was focused on determining the need for remediation in specific areas of the site, selecting and designing remedies, and evaluating the effectiveness of implemented actions.

- Initiating an interim remedial action provided for hydraulic containment and recovery of free-phase petroleum product and containment of a substantial portion of petroleum constituents dissolved in groundwater while the full extent of contamination and supplemental remedial actions were defined.

- Although the interim system operated a high percentage of the time, downtime and low flow rates caused by operating problems resulted in a partial loss of full hydraulic containment of the dissolved - phase contamination.

- Leasing the activated carbon system and carbon provided the flexibility to modify the treatment system in response to changing operating conditions and supplier performance.

Technology Limitations

- Regular treatment of recovery wells to remove solids buildup on intake screens and pump intakes (redevelopment and chemical treatment) is required to maintain adequate capture zone(s) at the Constantine site.

- Olephyllic/hydrophobic filter-skimmers were initially used to recover free product. Frequent maintenance was required due to solids buildup, and they were eventually replaced with free product recovery pumps.

- Paddle wheel-type flow sensors are less than ideal for this site due to in-line solids buildup.

- Carbon system operation is hydraulically limited by solids build-up. Laboratory analysis indicated the reddish/brown solids causing the fouling was mainly biomass (primarily aerobic iron and slime forming bacteria) bound with inorganic matter (iron, silica, sulfur, aluminum and calcium). Daily backwashing of the carbon vessels is required to maintain flow adequate for sustaining hydraulic containment.

- Activated carbon efficiency is limited by suspended solids buildup. Bag filters have only been partially successful in controlling the suspended solids loading to the carbon adsorbers. New methods to control influent solids are regularly evaluated.

- Granular activated carbon is inefficient in removing MTBE as compared to BTEX. An engineering analysis performed subsequent to installing the interim remediation system indicated that air stripping followed by aqueous phase activated carbon may be a more cost-effective technique for treating water with elevated MTBE concentrations.

- BTEX concentrations in groundwater near the source of contamination did not decrease substantially over a 5 (plus) year period. Pump and treat systems appear limited in their ability to restore groundwater quality due to ongoing solubilization of constituents from free product and residual contamination in saturated zone soils.

Future Technology Selection Considerations

- A phased approach to investigation and remediation at this site was beneficial. Early action to control contaminant migration in groundwater, when properly designed and implemented, can reduce the extent, duration and cost of clean up.

- The Constantine site SPDES permit restricted the volume of groundwater that could be extracted and treated, limiting the ability to modify system operation to expand the capture zone. Discharge permits for groundwater treatment systems should provide for sufficient capacity to accommodate modest increases in flow to achieve remediation objectives.

LESSONS LEARNED (Continued)

Future Technology Selection Considerations

- Substantial attention is paid to the design and construction of groundwater pump and treat systems. Greater attention should be paid to operation and maintenance, including periodic evaluation of the performance of subsurface and above ground system components (e.g., capture zone analyses, contaminant transport evaluation, treatment system removal efficiency, etc.), to ensure project objectives are met.

- The potential impact of solids buildup due to biomass growth and oxidation of inorganics should be addressed in the design of groundwater pump and treat systems.

- Ultrasonic flow meters should be considered for use in groundwater pump and treat systems where solids buildup is of concern.

- Alternative treatment systems (i.e., air stripping followed by aqueous-phase activated carbon polishing) should be considered for sites where efficient removal of MTBE is required prior to discharge.

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental
Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

CERTIFICATION

This analysis accurately reflects the performance and costs of the remediation:

x Paul F. Ressmeyer

Paul F. Ressmeyer
Remedial Project Manager
Amoco Corporation

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 1, 5, 7, and 23
Remediation System:	Source #s 1, 2, 3, 5, 7, 9, 17, 18, 20, 21, and 23
Performance:	Source #s 5, 6, 7, 10, 12, 14, 16, 17, 19, and 23
Cost:	Source #s 11, 13, 22, and 23
Regulatory/Institutional Issues:	Source #s 4, 5, 7, 8, 15, and 23
Schedule:	Source #s 5, 7, 19, 22, and 23
Lessons Learned:	Source #s 5, 6, 7, 10, 12, 14, 17, and 23

Chronological List of Sources and Additional References

1. *Design Basis for Constantine Remediation System*, prepared by Groundwater Technology, Inc., Undated.

2. *Plans and Specifications for Interim Remediation System*, prepared by Groundwater Technology, Inc., Undated.

3. *Operational and Maintenance Information for the Interim Groundwater Remediation and Hydrocarbon Treatment System* - Amoco, Florence Township near Constantine, Michigan, prepared by Groundwater Technology, Inc., March 8, 1988

4. *NPDES Permit No. MI0046159* - AMOCO Oil Co. - Constantine, Michigan, Water Resources Commission, issued September 30,1987, modified September 21,1989.

5. *Data Package*, prepared by J. W. Aiken and D. A. Schumacher, ENSR Consulting and Engineering, June 17, 1992.

6. *August 1991 Quarterly Monitoring Report* - Constantine, Michigan Site, Document 0350-020-400, prepared for AMOCO Corporation, prepared by ENSR Consulting and Engineering, May 1992.

7. *Remediation Plan for Constantine, Michigan, Document Number 0350-024-141*, prepared by ENSR, January 1992.

8. *MERA Operational Memorandum #8 - Type B Criteria, Rules 299.5709, 299.5711(2), 299.5711(5) and 299.5713, Interoffice Memorandum*, prepared by Alan J. Howard, Michigan Department of Natural Resources, January 8, 1992.

9. *Summary of Recovery Well Installations at Constantine, Letter to Mr. Paul Ressmeyer, Amoco Corporation*, prepared by Mr. David A. Schumacher, ENSR Consulting and Engineering, March 26,1992.

10. *November 1991 and February 1992 Quarterly Monitoring Report - Constantine, Michigan Site Document No. 0350-020-110*, prepared by ENSR Consulting and Engineering, May 1992.

11. *Irrigation Well Drilling at Constantine, Letter to Mr. Paul Ressmeyer, Amoco Corporation*, prepared by Messrs. Joseph W. Aiken and David A. Schumacher, ENSR Consulting and Engineering, June 17, 1992.

12. *Spent Granular Activated Carbon: Foulant Analysis, Constantine Site, Michigan; Project 2112-21-D703, Internal Memorandum to P.F. Ressmeyer, Amoco Corporation*, prepared by V.E. Berkheiser, July 20,1992.

13. *Calgon Carbon Service Agreement, Letter to Paul Ressmeyer, Amoco Corporation*, prepared by M.C. Reiser, January, 1993.

14. *Semi-Annual Monitoring Report, Constantine Michigan, Period of April 1993 through October 1993*, prepared by Amoco Corporation, January 30, 1993.

15. *NPDES Permit No. MI0046159. - Amoco Pipeline Company, 63638; Constantine Road, Constantine, Michigan*, Water Resources Commission, March 18, 1993.

16. *Semi-Annual Monitoring Report - Constantine, Michigan, 9/93 to 3/93*, prepared by Amoco Corporation, June 8, 1993.

17. *AMOCO Constantine Site, Presentation Handout* prepared by Calgon Carbon, June 22,1993.

18. *Work Plan for Remedial Design/Remedial Action - Constantine, MI* Residuals Management Technology, Inc., August 1993.

19. *AMOCO, Constantine, Michigan - Results of Air Sparging Pilot Test*, Letter to Ms. Lolita M. Anderson, Superfund Coordinator, Amoco Corporation, prepared by Residuals Management Technology, Inc., September 7, 1993.

20. *Project Manual for Amoco Corporation Air Sparging System, Final Design - Phase 1 Constantine, Michigan*, prepared by Residuals Management Technology, Inc., October 1993.

21. *Specifications for AMOCO Corporation Air Sparging System, Final Design - Phase 2, Constantine, Michigan*, prepared by Residuals Management Technology, Inc., October 1993.

22. *Constantine Michigan Air Sparging System - Project Summary*, Letter to Ms. Lolita Anderson, Superfund Coordinator, Amoco Corporation, prepared by Residuals Management Technology, Inc., January 5, 1994.

23. Personal Communications with Mr. Paul F. Ressmeyer, Superfund Coordinator, Amoco Corporation, March through June 1994.

Pump and Treatment System at Commencement Bay, South Tacoma Channel (Well 12A), Phase 2, Tacoma, Washington (Interim Report)

Case Study Abstract

Pump & Treatment System at Commencement Bay, South Tacoma Channel (Well 12A) Phase 2, Tacoma, Washington

Site Name:
Commencement Bay, South Tacoma Channel (Well 12A) Superfund Site

Location:
Tacoma, Washington

Vendor:
Not Available

SIC Code:
2851 (Paints, Varnishes, Lacquers, Enamels, and Allied Products)

Waste Source:
Storage - Drums; Other: Pour off from Processing Tanks

Purpose/Significance of Application:
Application of groundwater extraction followed by granular activated carbon treatment of extracted groundwater. Project completed in conjunction with an ongoing soil vapor extraction system.

Contaminants:
Chlorinated Aliphatics
- trans-1,2-Dichloroethene (DCE), 1,1,2,2-Tetrachloroethane (PCA), 1,1,2,2-Tetrachloroethane (PCE), Trichloroethene (TCE)
- PCA contamination plume measured at levels greater than 10,000 µg/L in July 1983
- Free phase estimates of contamination are PCE - 3734 lbs, TCE - 126,112 lbs, and PCA - 209,115 lbs
- Remedial investigation showed DCE up to 100 ppb; PCA up to 300 ppb; PCE up to 5.4 ppb; and TCE up to 130 ppb in Well 12A

Technology:
Groundwater Extraction followed by Granular Activated Carbon (GAC)
- 7 groundwater extraction wells with a 500 gpm design flow rate
- Designed to have drawn-down sufficient to create a cone of depression and to reduce further migration of contaminants out of the source area
- 2 liquid-phase GAC containers operated in parallel
- Treated water discharged to a storm drain system
- Soil vapor extraction used in a related application to remove volatile contaminants from the soil matrix

Type/Quantity of Media Treated:
Groundwater
- Upper aquifer (50 ft thickness) consists of unconfined sand and gravel
- Depth to water table approximately 36 feet
- Lower aquifer not contaminated
- Separate liquid phases of VOCs in soil and groundwater suspected
- Area suspected of groundwater contamination covers approximately 100 acres

Period of Operation:
Status: Ongoing
Report covers - 1988 to 2/94

Cleanup Type:
Full-scale cleanup (interim results)

Cleanup Authority:
CERCLA; Local Requirements
- ROD Date: 3/85

Point of Contact:
Kevin Rochlin
Remedial Project Manager
U.S. EPA Region 10
Seattle, Washington

Case Study Abstract

Pump & Treatment System at Commencement Bay South Tacoma Channel (Well 12A), Phase 2, Tacoma, Washington

Regulatory Requirements/Cleanup Goals:
- Cleanup goals identified for Well 12A (City of Tacoma production well) based on ARARs for RCRA, CAA, and CWA:
  - if Well 12A is used for drinking water - 10^{-6} risk level for contaminants present
  - if not, groundwater corrective action required until the concentration of hazardous constituents meets one of the following: MCLs, ACLs, or background
- Prior to discharge to storm sewer, extracted water required to meet EPA standards for "Fish Consumption Only", including DCE at 1.85 µg/L; PCA at 10.7 µg/L; PCE at 8.85 µg/L; TCE at 80.7 µg/L; discharge rate of 500 gallons per minute; pH of 6 to 9; TSS < 500 mg/L, and total VOAs of < 1mg/L

Results:
As of February 1994:
- 281,700,000 gallons of groundwater have been pumped and treated
- An estimated 10,361 pounds of VOCs have been removed by the GAC system
- Specific VOCs in GAC system influent ranged from 13 µg/L to 2,000 µg/L
- Specific VOCs in GAC system effluent ranged from <1 µg/L to 13 µg/L

Cost Factors:
- Total Capital Costs (contract amount) - $1,343,701 (as of 7/25/88)
- No information provided on operating costs, cost sensitivities, or breakdown of capital costs

Description:
The Commencement Bay site was used from 1927 to 1964 for waste oil recycling, paint and lacquer thinner manufacturing, and solvent reclamation. Hundreds of drums of material were stored at this site. Leaks from these drums, as well as the dumping of wastes directly on the ground and overflows from the solvent and waste oil recycling tanks, resulted in contamination of the soil and groundwater at the site. The primary contaminants of concern at the site included DCE (trans-1,2-dichloroethene), PCA (1,1,2,2-tetrachloroethane), PCE (1,1,2,2-tetrachloroethene), and TCE (trichloroethene). A PCA groundwater contamination plume was measured at levels greater than 10,000 µg/L and a separate liquid phase of contamination was suspected in both the soil and groundwater. In addition, chlorinated hydrocarbons were detected in a City of Tacoma production well (Well 12A) in 1981. The site was placed on the National Priorities List (NPL) and a Record of Decision was signed in 1985.

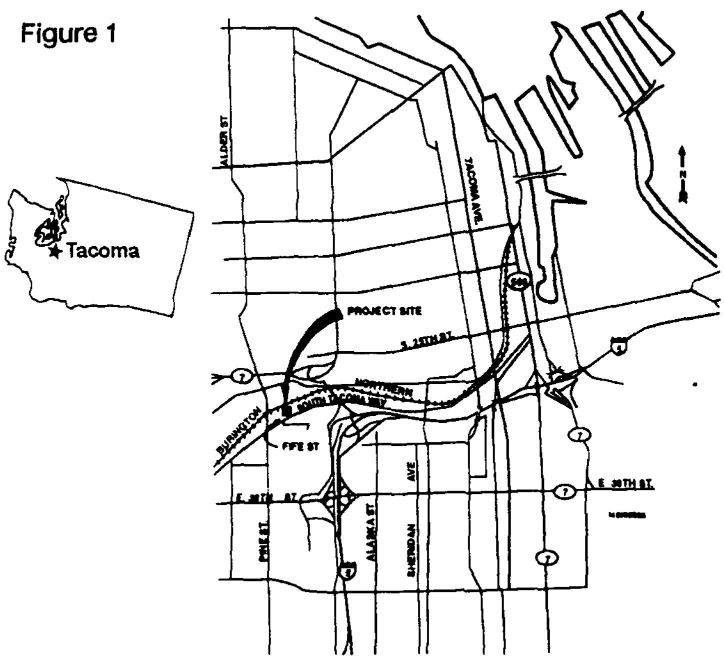
A groundwater extraction system using granular activated carbon (GAC) for treatment of extracted groundwater was installed and began operating at the site in 1988. This system includes 7 groundwater extraction wells and a 500 gpm design flow rate, and was designed to have a draw-down sufficient to create a cone of depression and to reduce further migration of contaminants out of the source area. Treated water is discharged into a storm drain system. The groundwater remediation was ongoing at the time of this report.

As of February 1994, approximately 282,000,000 gallons of groundwater had been extracted, and an estimated 10,631 pounds of VOCs removed by the GAC. Specific VOCs in the GAC system influent ranged from 13 µg/L to 2,000 µg/L, and, in the effluent, from <1 µg/L to 13 µg/L. The contract amount for total capital cost was identified as $1,343,701, as of July, 1988.

TECHNOLOGY APPLICATION ANALYSIS

SITE

Figure 1



TECHNOLOGY APPLICATION

This analysis covers the field application of system to pump & treat the groundwater in a carbon adsorption system in an above ground plant. This began in late 1988 and Phase II is ongoing.

The contaminated soil matrix at this site is being remediated through *in situ* soil vapor extraction (SVE) which is not included in this analysis.

SITE CHARACTERISTICS

Site History/Release Characteristics

During the period from 1927 to 1964 this site was used by National Oil and Paint for waste oil recycling, paint and lacquer thinner manufacturing, and solvent reclamation. The site was purchased by the Time Oil Company in 1964.

The pre-1964 operations appear to have contributed to the site VOC contamination in several ways. First, the site was used to store hundreds of drum of potentially "useful" materials. Some of the stored drums leaked. Non-useable materials were dumped directly onto the ground. Second, during the recycling process for waste oil, solvents contained in the oil floated to the top of the processing tank and were poured off. Periodically, the tank holding the solvents overflowed onto the site.

In 1981 chlorinated hydrocarbons were detected in groundwater samples from the City of Tacoma production well 12A.

This site is in the City of Tacoma, Washington, and includes industrial, commercial, and residential areas that surround the site. Well 12A is one of 13 wells used by the city to meet peak summer and emergency water demands.

In 1983 a five tower air stripping system was built to treat well 12A water. In 1988 a pump and treatment system was installed near the contamination source to intercept and treat the groundwater plume.

In accordance with the Record of Decision (ROD), signed in 1985, soils and solid waste materials were disposed of in an offsite Resource Conservation and Recovery Act (RCRA) approved facility. This waste material was contaminated with heavy metals (primarily lead).

Contaminants of Concern

The VOCs of greatest concern in the soil and groundwater are the following chlorinated hydrocarbons:

DCE (trans-1,2-dichloroethylene)

PCA (1,1,2,2-tetrachloroethane)

PCE (1,1,2,2-tetrachloroethylene)

TCE (trichloroethylene)

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Property at 1 atm	Units	DCE	PCA	PCE	TCE
Empirical Formula		$C_2H_2Cl_2$	$C_2H_2Cl_4$	C_2Cl_4	C_2HCl_3
Density	g/cm^3	1.257	1.586	1.6311	1.462
Melting Point	°C	-50	-43.8	-22.4	-84.8
Vapor Pressure @ 25°C	mm Hg	331	419	77	
Henry's Law Constant	$\frac{(atm)(m^3)}{mole}$	$5.32X10^{-3}$ @ 25 °C	$3.81X10^{-4}$ @ 20 °C	$2.87X10^{-2}$ @ 25 °C	$1.17X10^{-2}$ @ 25 °C
Water Solubility	mg/l	600 @ 20 °C	2,900 @ 20 °C	150 @ 25 °C	1,100 @ 25 °C
Log Octanol-Water Partition Coefficient;	log Kow	1.48	2.39	2.53	2.53
Organic Carbon Partition Coefficient; Koc,	L/kg	118	364	126	
Site Specific Extraction Efficiency, %		7	2	2	

Nature & Extent of Contamination

- About 20% of the contamination is in the top 32.5 feet, and the remaining 80% is in the 32.5 to 40 feet depth interval.
- The volume of contaminated soil is (66,287 ft2 X 40 ft deep =) 2,651,480 ft3.
- For the VOCs, there may be separate liquid phases of these compounds or miscible solutions between them in both the soil and groundwater.
- Free phase estimates are 3,734 pounds of PCE; 126,112 pounds of TCE; and 209, 115 pounds of PCA.
- Total semi-volitile organic compounds (SVOCs) for the site is roughly 420 pounds.
- Gas chromatography limitations resulted in the PCA concentrations reported actually being PCA and/or PCE.

Contaminant Locations and Geologic Profiles

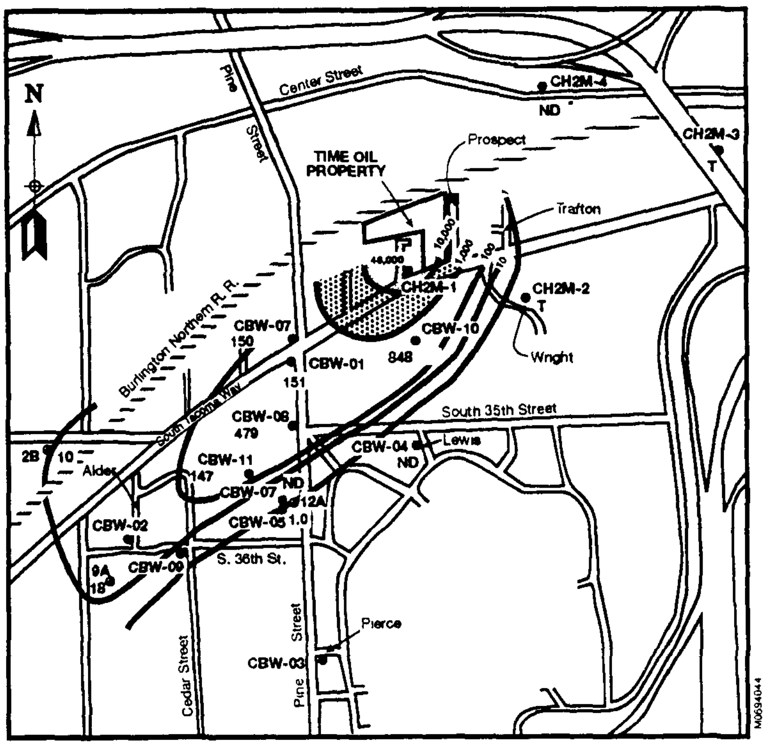
Remedial investigation (RI) field activities at the site found the following concentrations:

Contaminant	Water from Well 12A Concentration, ppb	Railroad Spur Fill soil Concentration, mg/kg
DCE	30 to 100	3.92
PCA	17 to 300	*1,030
PCE	1.6 to 5.4	*1,030
TCE	54 to 130	160

* PCA and/or PCE

Spatial Distribution of the Contaminants of Concern

Figure 2



LEGEND
- Monitoring Wells From Previous Investigation
- City of Tacoma Wells

PCA Contamination Plume July 1983

Note: All concentration values are micrograms per liter (µg/l).

- All of the contaminants of concern have a solubility in water of 150 mg/l (PCE) or more (up to 2,900 mg/l for PCA).
- Groundwater underlying the Time Oil Company property and adjacent properties to the south appears to be the most contaminated.

Hydrogeologic Units

- The upper aquifer (unconfined sand and gravel) is 50 feet thick (depth to the water table is about 36 feet).
- The upper aquifer is separated from the lower aquifer by a 40 foot thick dense glacial till aquitard.
- The lower aquifer is not contaminated.
- The area suspected of groundwater contamination is in the upper aquifer and covers about 100 acres and is bounded by the city water well field on the south, the Burlington Northern Railroad on the north, and Interstate 5 on the East.
- Figure 2 shows the contamination plume for PCA which is typical for the VOC groundwater contamnation at this site.

Site Conditions

- Average Air Temperature 38°F (Jan.) to 65°F (July)
- Precipitation
  - Annual Average 38. in.
  - December Average 6.3 in.
  - July Average 0.8 in.
- Snowfall, Annual Average 14. in.
- Relative Humidity, Average 65% to 85%
- Wind Speed, Average 10 mph
- Project site elevation is 270 feet.
- The vadose zone thickness (depth to groundwater) varies from 33 to 40 feet.
- The groundwater gradient is about 0.05%, falling to the north-northeast.

Key Soil or Key Aquifer Characteristics

Property	Units	Range or value
Porosity	%	30
Particle density	g/cm^3	2.65
Soil bulk density	g/cm^3	1.86
Surface soil permeability	cm/sec	2.8 to 3.6 X 10^{-3}
Depth to groundwater	ft	36
Aquifer thickness	feet	50
Water Saturated thickness	feet	10 to 17

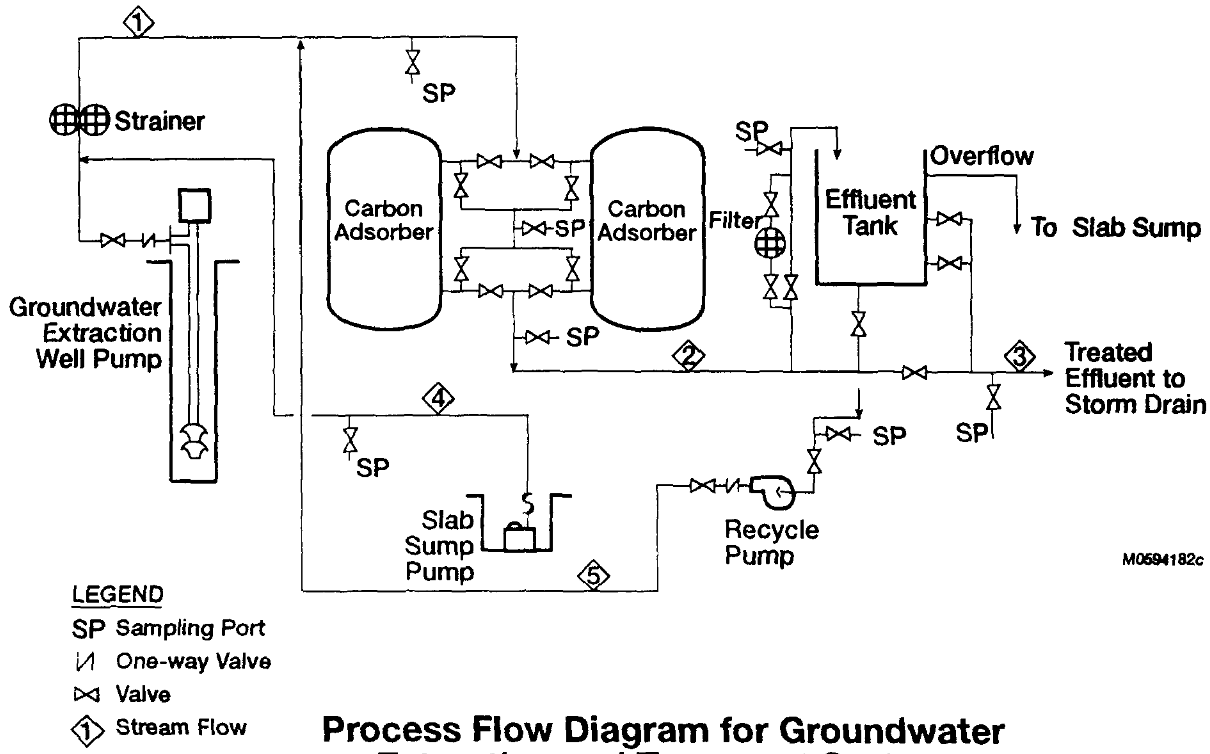
TREATMENT SYSTEM

The selected remedial action includes:

- Groundwater treatment by a liquid phase granulated activated carbon (GAC) adsorption system (predicted >98% removal), discussed in this report.
- Treated water is disposed of in the storm drain system .
- Monitor groundwater for VOCs and, after 2 years of operation, evaluate the effectiveness of the groundwater extraction and treatment system.
- Prohibit withdrawal of groundwater by private parties where the hazard > 10^{-6}.
- Use soil vapor extraction (vacuum applied via extraction wells that extend to the groundwater), described in a separate report to remove volatile contaminants in the soil matrix.

Overall Process Schematic

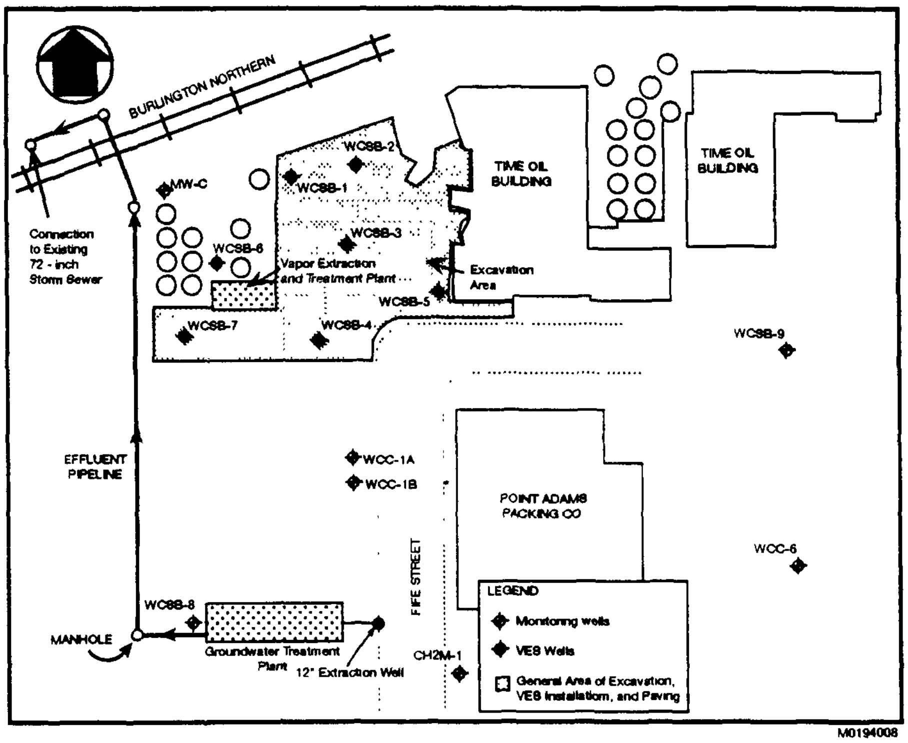
Figure 3



Process Flow Diagram for Groundwater Extraction and Treatment System

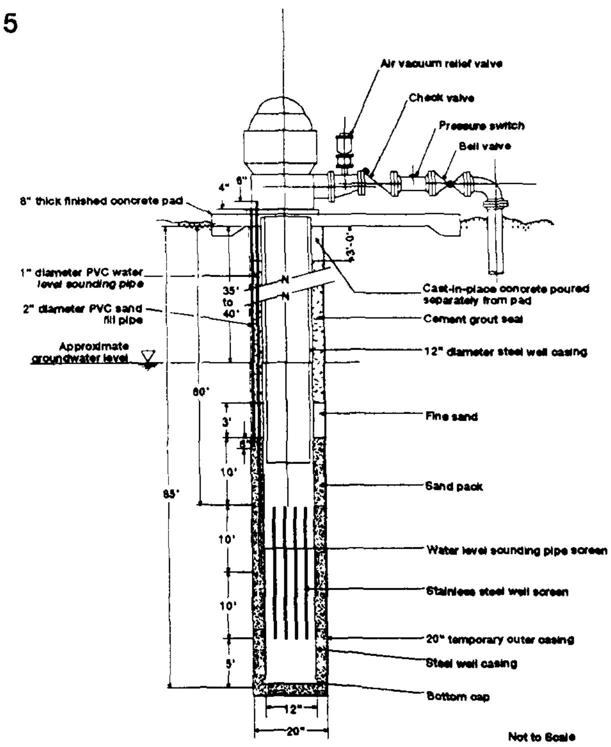
System Closeup

Figure 4



LOCATION OF EXCAVATION AREA AND TREATMENT SYSTEMS

Figure 5



Groundwater Extraction Well

Key Design Criteria

- The extraction system is designed to have sufficient draw-down to create a cone of depression to reduce further migration of contaminants out of the source area.
- A pumping rate of 200 gpm is estimated to induce a 0.75 foot draw down at a radius of influence of 200 feet, and a pumping rate of 500 gpm is estimated to induce 1.9 feet of draw down at a radius of influence of 200 feet. 500 gpm was selected as the design flow rate.
- A radius of influence of 200 feet is expected to largely prevent further contamination from leaving the source area.
- The adsorption capacity of granular activated carbon for PCA is given by the equation mg PCA adsorbed/g GAC = 12.8(mg/L of PCA in water)0.613

EXPECTED FLOWRATES AND CONCENTRATIONS OF CONTAMINANTS FOR THE TREATMENT SYSTEM

Stream Number*	1	2	3	4	5
Maximum Flowrate (gpm)	500	500	500	20	200
Concentration of Volatile Organic Compounds, mg/l					
1,1,2,2-Tetrachloroethane (PCA)	2-35	0.3	0.3	—	—
Trans-1,2-Dichloroethylene (DCE)	0.2-3.5	0.03	0.03	—	—
Trichloroethylene (TCE)	0.4-6.5	0.06	0.06	—	—
Tetrachloroethylene (PCE)	0.4-0.7	.01	.01	—	—

*Stream number explanation (see also figure 3):

1. Groundwater from extraction well.
2. Treated groundwater leaving GAC adsorbers.
3. Effluent to storm drain.
4. Slab sump pump to strainer and GAC adsorbers.
5. recirculating water to GAC adsorbers.

Key Monitored Operating Parameters

- Groundwater monitoring wells located in the vicinity of the Time Oil Company will be used to observe the effectiveness of the extraction system in creating a capture zone that will effectively reduce contaminant concentration outside the source area.
- The groundwater treatment plant discharge shall meet the EPA standards for the storm water discharge, maximum permitted concentrations (for "Fish Consumption Only"):

Compound	Permitted Concentration, μg/L
DCE	1.85
PCA	10.7
PCE	8.85
TCE	80.7

Other limitations include:

maximum discharge rate	500 gallons/minute,
pH	6 to 9,
total suspended solids	< 500 mg/L
total VOAs	<1 mg/L

PERFORMANCE

Performance Objectives

- Create a cone of depression that would reduce further migration of contaminants out of the source area.
- Treat the contaminated groundwater to reduce volatile organic compounds to meet the EPA standards for the storm water discharge.

Treatment Plan

- Contaminated groundwater is being treated to remove VOCs by pumping contaminated groundwater out of the source area through a GAC adsorption system.
- The groundwater treatment plant discharge is meeting water quality criteria for protection of human health at a 10^{-4} cancer risk for human ingestion of aquatic organisms (45 FR 79318, November 28, 1980), as follows:

Compound	Permitted Concentration, µg/L
Vinyl chloride	525
PCA	10.7
TCE	80.7
Other permit limitations include:	
pH	6 to 9

Operational Performance

Volume of Water Pumped

- As of 23 Feb. 1994, 281,700,000 gallon of groundwater have been pumped and treated by the GAC treatment system.

System Downtime

- No down time was reported for the period January 1994 through February 1994.
- The EPA has provided no other Activities Reports for this project. (Figure 6 suggests a period of downtime from early to middle 1990.)

Treatment Performance

Effects on Plume

- A pumping rate of 500 gpm was estimated to induce 1.9 feet of draw down at a radius of influence of 200 feet.
- The EPA has provided no documents or data relative to the cone of influence resulting from pumping of the groundwater.

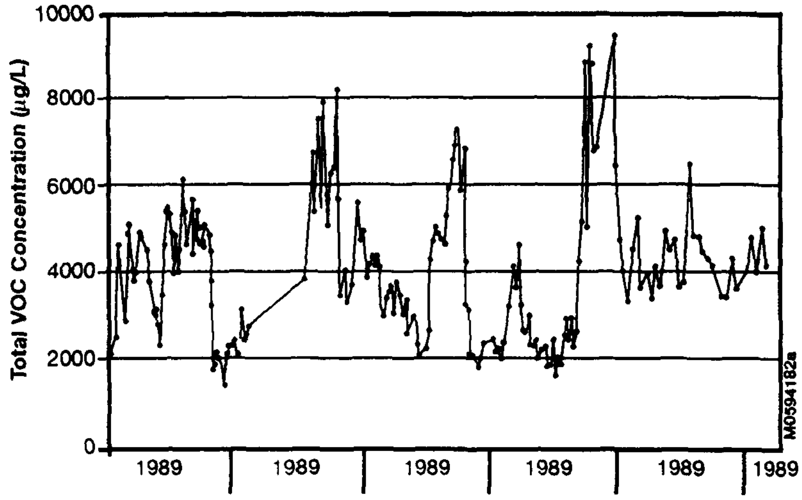
Contaminants versus Time at the Treatment Plant Influent

- Figure 6 shows the total VOC concentration for the period 1989 through February 1994.

Influent versus Effluent

- The following table gives the results of the groundwater GAC treatment for the period 11 January 1994 through 23 February 1994

Figure 6
Total VOC Influent Concentrations, 1989 Through Currrent



VOCs IN GAC TREATMENT SYSTEM INFLUENT AND EFFLUENT

Concentration of VOCs, ug/l				Date
GAC System Influent	1/11/94	1/26/94	2/8/94	2/23/94
Vinyl Chloride	21	16	32	29
Trans-1,2-Dichloroethylene	290	270	280	270
Cis-1,2-Dichloroethylene	240	210	200	200
Trichloroethylene	1,200	1,000	1,200	920
1,1,2-Trichloroethylene	15	10	15	13
Tetrachloroethylene	46	43	57	45
1,1,2,2-Tetrachloroethane	3,000	2,400	3,300	2,000
GAC System Effluent				
Vinyl Chloride	3.2	5.9	9.6	13
Trans-1,2-Dichloroethylene	<1	<1	<1	<1
Cis-1,2-Dichloroethylene	<1	<1	<1	<1
Trichloroethylene	8.4	8.1	11	6.9
1,1,2-Trichloroethylene	<1	<1	<1	<1
Tetrachloroethylene	<1	<1	<1	<1
1,1,2,2-Tetrachloroethane	<1	3.9	8.5	2.2

Total Pounds Contaminants Removed

- As of 23 Feb. 1994, an estimated 10,361 pounds of VOCs have been removed by treatment by the GAC treatment system. This estimates is based on the average loading rate of the GAC as calculated by periodic sampling.

COST

The U.S. EPA Region 10, Hazardous Waste Division declined to provide a breakdown of the capital estimate or the operating cost estimate. It also declined to provide cost data for the period since the remediation phase of the project started and access to the remediation contractor.

Capital Costs

	Original (4/5/88)	Current (7/25/88)
Contract Amount	$987,789	$1,343,701

(reference 7)

Operating Costs

NONE PROVIDED.

Cost Sensitivities

NONE PROVIDED.

REGULATORY/INSTITUTIONAL ISSUES

- Highly contaminated surface soils were transported to a RCRA approved landfill facility for treatment/disposal
- ARARs include RCRA, Clean Air Act regulations (for emissions of VOCs), the Clean Water Act, and the Safe Drinking Water Act (there are no drinking water standards for the contaminants present in Well 12A).
- If groundwater from Well 12A is to be used for drinking water, then it must be treated to the 10-6 risk level for the contaminants present. Otherwise, in order to be consistent with 40 CFR 264, Subpart F, groundwater corrective action is required until the concentration of hazardous constituents complies with one of the following: MCLs (where designated for particular substances), ACLs (that provide adequate protection of public health and the environment), or background.
- NPL site.
- The EPA standard for "Fish Consumption Only" was used for the storm water discharge maximum permitted concentrations:

Compound	Permitted Concentration, µg/L
DCE	1.85
PCA	10.7
PCE	8.85
TCE	80.7

Other limitations include:	
maximum discharge rate	500 gallons/minute,
pH	6 to 9,
total suspended solids	< 500 mg/L
total VOAs	<1 mg/L

SCHEDULE

None provided.

LESSONS LEARNED

- The project is not complete as yet.
- An operational analysis from which Lessons Learned could be derived has not been provided by the Region 10 of the U.S. EPA

SOURCES

Major Sources For Each Section

Site Characteristics:	2 and 9
Treatment System:	2 and 3
Performance:	4
Cost:	4 and 7
Regulatory/Institutional Issues:	1, 2, 5 and 6
Schedule:	None
Lessons Learned:	None

Chronological List of Sources and Additional References

1. EPA Superfund Record of Decision: South Tacoma Channel-Well 12A, WA, EPA/ROD/R10-85/OO4, May, 1985.
2. Revised Remedial Design Report, South Tacoma Channel Well 12A, by Woodward-Clyde Consultants for U.S. Army Corps of Engineers, Superfund Branch, Kansas City, Missouri District, April 17, 1987.
3. Letter from Philip N. Stoa, EPA Coordinator, Construction Division, Construction Services Branch, Seattle District, Corps of Engineers, December 15, 1993.
4. Fax from Kevin Rochlin, Region 10 U.S. EPA, Hazardous Waste Division, dated 18 May 1994.
5. RREL Treatability Data Base, Version 4.0, EPA, November 15, 1991.
6. Climates of the States, by the National Oceanic and Atmospheric Administration, US Department of Commerce, published by the Water Information Center, 1974.
7. Fax from Bill Brooker, Fort Lewis Area Office, Corps of Engineers, 10 May 1994.

ANALYSIS PREPARATION

This analysis was prepared by:
Stone & Webster Environmental Technology & Service
P.O. Box 5406
Denver, Colorado 80217-5406
Contact: Dr. Richard Carmichael 303-741-7169

REVIEW

Support and review for the preparation of this report was provided by

Kevin Rochlin
Project Manager
U.S. EPA, Region 10
Seattle, Washington

Recovery of Free Petroleum Product
Fort Drum, Fuel Dispensing Area 1595
Watertown, New York
(Interim Report)

Case Study Abstract

Recovery of Free Petroleum Product
Fort Drum, Fuel Dispensing Area 1595, Watertown, New York

Site Name: Fort Drum Fuel Dispensing Area 1595	**Contaminants:** Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX) - Gasoline and #2 fuel oil - Free product measured in two wells in 1990 and 1994 - Full extent of contamination not yet defined	**Period of Operation:** Status: Ongoing Report covers - 2/92 to 4/94
Location: Watertown, New York		**Cleanup Type:** Full-scale cleanup (interim results)
Vendor: Not Available	**Technology:** Groundwater Extraction followed by Air Stripping and Granular Activated Carbon - 2 recovery wells - approximately 25 ft. below ground surface; average rate of 5-6 gpm - Oil/water separator - 575 gallon capacity - Air stripper - 750 cfm - GAC - 4 55-gallon steel drums; 200 lb GAC per drum; operated 2 in series	**Cleanup Authority:** DoD
SIC Code: 9711 (National Security)		**Point of Contact:** Remedial Project Manager Fort Drum Environmental Division Watertown, NY
Waste Source: Underground Storage Tank	**Type/Quantity of Media Treated:** Groundwater and Free Product - Hydraulic conductivity of aquifer 0.11 to 0.0012 cm/sec - Transmissivity 11,787 to 32,518 using Jacob method	
Purpose/Significance of Application: Full-scale remediation to recover free-phase petroleum product using groundwater extraction and air stripping and granular activated carbon (GAC).		

Regulatory Requirements/Cleanup Goals:
- Final cleanup criteria have not been established at this time; the project is being conducted as a Rapid Response Interim Remediation
- Treated water discharged to the POTW must meet the following criteria - benzene (3 μg/L), toluene (35 μg/L), xylenes (190 μg/L), ethylbenzene (8 μg/L)

Results:
- Information on the total quantity of free product recovered is not available at this time
- The effluent from the treatment system met all discharge criteria

Cost Factors:
- Total Capital Costs - $958,780 (including system design and construction including site work, equipment, and mobilization/demobilization)
- Total Annual Operating Costs - $129,440 (including carbon changeout/regeneration, maintenance, laboratory analysis, and project management)
- An estimated cost for completion of the cleanup is not available at this time

Recovery of Free Petroleum Product, Fort Drum, Fuel Dispensing Area 1595, Watertown, New York (Continued)

Description:
Fort Drum in Watertown, New York, established in 1906, serves as a combat skills training area and operations headquarters for light infantry troops. Motor vehicle and aircraft refueling activities are conducted in Area 1595 of the facility. Area 1595 includes an underground storage tank (UST) and 10 dispensing units for gasoline, diesel fuel, and jet fuel. In 1982, free petroleum product was observed in a spring near this area. Suspected contaminant sources include leaking USTs and wastewaters from vehicle washing operations located adjacent to Area 1595. The primary contaminants of concern are BTEX (benzene, toluene, ethylbenzene, and xylenes) and free petroleum product. The full extent of the contamination had not been defined at the time of this report. The site remediation is being performed as a Rapid Response Interim Remediation and final cleanup criteria have not been established at this time.

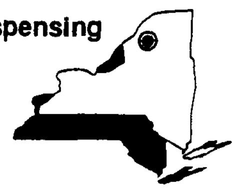
A pump and treat recovery, consisting of two recovery wells, an oil/water separator, an air stripper, and granular activated carbon vessels, was operated from March 1992 to mid-1993. The system was restarted in February 1994 and was operational at the time of this report. The first year of operation focused on troubleshooting and little data were collected during that time. As such, no information is available at this time on the total quantity of free product recovered or the rate of recovery. Data from the air stripper/GAC system indicated that the concentrations of contaminants in the effluent meet the POTW discharge criteria for BTEX. An air emissions certificate was issued by the State in October 1992; however, information on specific emission limits was not available at the time of this report.

The total capital costs for this remediation are $958,780 and the estimated total annual operating costs are $129,440. Based on operations to date, it has been observed that free product recovery pumps require frequent maintenance and that activated carbon efficiency was limited because of fouling by iron and biomass.

TECHNOLOGY APPLICATION ANALYSIS

SITE

Fort Drum, Fuel Dispensing Area 1595
Watertown, NY



TECHNOLOGY APPLICATION

This analysis covers an effort to recover **free phase petroleum product** using an interim groundwater **pump and treat system. Air stripping** and **granular activated carbon (GAC)** have been used in series to treat recovered groundwater. Interim remediation was first initiated in February 1992. This analysis covers performance through April 1994.

SITE CHARACTERISTICS

Site History/Release Characteristics

- Fort Drum, a U.S. Armed Forces Command installation, was originally established in 1906 as a National Guard training area and has served as a combat skills training area and operations headquarters for light infantry troops.
- Motor vehicles and aircraft refueling at Fort Drum took place at nine dispensing facilities located along a 2-mile strip of land known as "Gasoline Alley." Fuel Dispensing Area 1595 (Area 1595), the subject of this report, is located along a portion of Gasoline Alley
- Area 1595 consists of an underground storage tank (UST) area approximately 150 feet in length, and a dispensing area with 10 dispensing units spread over a distance of approximately 400 feet.
- In 1982, free petroleum product was observed discharging from a natural spring located 550 feet northwest of the underground storage tanks (USTs) which supplied gasoline, diesel fuel and jet fuel to the Area 1595 dispensers.
- The precise source of the free product could not be found. A 1" diameter hole was discovered in an UST removed in 1975. All of the USTs were reported to have been replaced by 1985. The tanks on site passed a leak test in March 1991, but the system piping was determined to have a leak rate of 0.05 gallons/hour. The current status of the USTs is unknown.
- Several former washracks located next to Area 1595 may also have been a source of oil and other materials discharged to the subsurface. The washracks were used to clean wheeled and track vehicles.
- An earthen dike was constructed immediately downstream of the spring to facilitate the surface collection and skimming of free petroleum product. The interim groundwater pump and treat system addressed in this report was constructed in 1991 to recover free product from the subsurface.

Contaminants of Concern

Contaminants of concern focused on during the groundwater remediation are:

Benzene
Toluene
Ethylbenzene
Xylene-m (1,3)
Xylene-o (1,2)
} BTEX

Free petroleum product, a source of the contaminants identified above, was also of concern.

Contaminant Properties

Property at STP*	Units	B	T	E	X***
Empirical Formula	-	C_6H_6	$C_6H_5CH_3$	$C_6H_5CH_3$	$C_6H_4(CH_3)_{2m}$
Density	g/cm^3	0.87	0.87	0.87	~0.87
Vapor Pressure	mmHg	75	29	7	10
Henry's Law Constant	$atm{\cdot}m^3/mole$	5.6E-3	6.5E-3	8.4E-3	2.5E-1
Water Solubility	mg/L	1,780	534	161	178
Octanol-Water Partition Coefficient; K_{ow}	-	132	490	1,413	1,830
Organic Carbon Partition Coefficient; K_{oc}	-	50	339	565	255

**STP = Standard Temperature and Pressure; 1 atm, 25 °C*
*** Properties at 20°C ***Mixture of m,o and p-xylenes*

Nature & Extent of Contamination

- Laboratory analytical results have indicated that the detected petroleum contamination is gasoline and #2 fuel oil. The free product and the petroleum-contaminated soil and groundwater in Area 1595 appears to be located in a narrow zone hydraulically downgradient and downstream from the fuel dispensing area.
- Petroleum hydrocarbons and lead have been detected in surface water and sediment samples collected from the stream at locations downstream from the dike.
- The full extent of contamination has not yet been defined.
- A preliminary human health risk assessment indicated that petroleum contamination poses an increased lifetime cancer risk of > $1x10^{-6}$.

Contaminant Locations and Geologic Profiles

Remedial investigation field activities at the site have included a shallow soil vapor survey; the excavation of shallow test pits, soil borings and groundwater monitoring wells; free product gauging; water level elevation measurements; and the collection and laboratory analysis of surface water, sediment, soil, and groundwater samples. Some of the data is summarized in this report to provide a conceptual understanding of site conditions.

Site Layout and Surface Water/Sediment Contamination (Plan View)

Benzene, toluene, xylenes, total volatile aromatic hydrocarbons and lead were detected in surface water. Toluene, xylenes and total volatile aromatic hydrocarbons were detected in sediment samples.

Legend

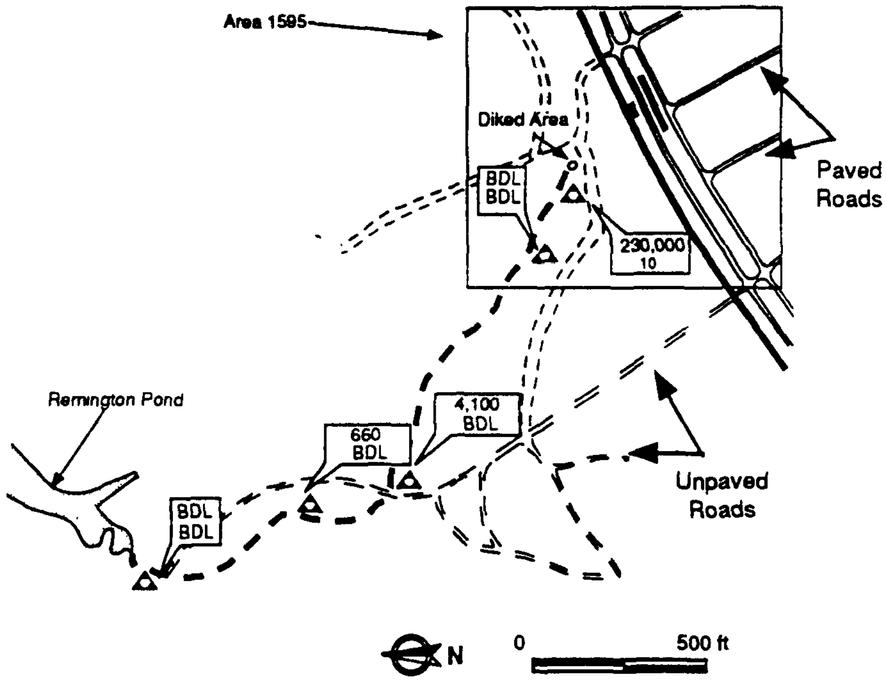
- Surface Water Route
- Sample Location

Total Volatile Aromatic Hydrocarbons (EPA method 503.1)

10 Sediment Concentration mg/kg
51 Surface Water Concentration mg/L

BDL = Below Detection Limit

All Results: December 1989



Soil Contamination (Plan View)

Evidence of subsurface soil contamination associated with petroleum was found in soil samples collected from shallow test pits and soil borings in December 1989.

Legend

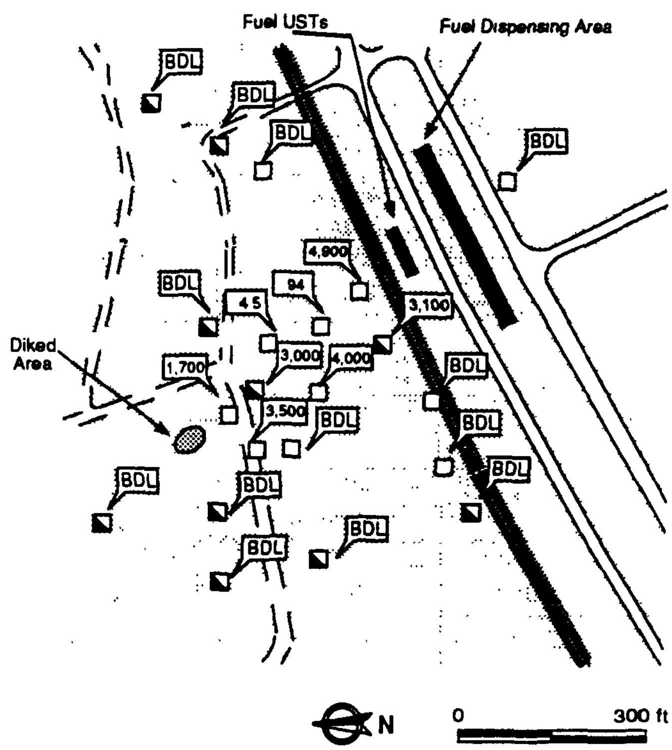
All Values Indicate Total Volatile Hydrocarbons (EPA Method 503.1)

- Soil Test Pit Location
- Soil Boring Location

1,000 Concentration in Soil (mg/kg)

BDL = Below Detection Limit

All results: December 1989



Contaminant Locations and Geologic Profiles (Continued)

Free Floating Product and Groundwater Contamination (Plan View)

Free product was measured in two of the Area 1595 monitoring wells in 1990. Benzene, toluene, ethylbenzene, xylenes, total volatile hydrocarbons and lead were detected in groundwater samples during late 1989/early 1990.

All of the monitoring wells were again gauged for free product on April 4, 1994; two of the wells within 150 ft. of the former fuel USTs contained free product– one with 7.25 inches, and the other with 3.5 feet.

Legend

All Values Indicate Total Volatile Aromatic Hydrocarbons

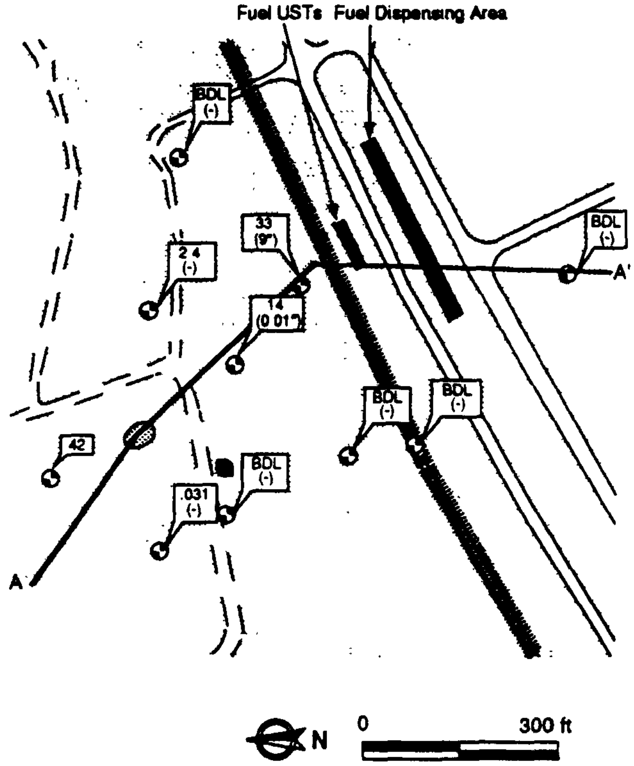
Groundwater Sample Location

A—— A' Cross Section Location

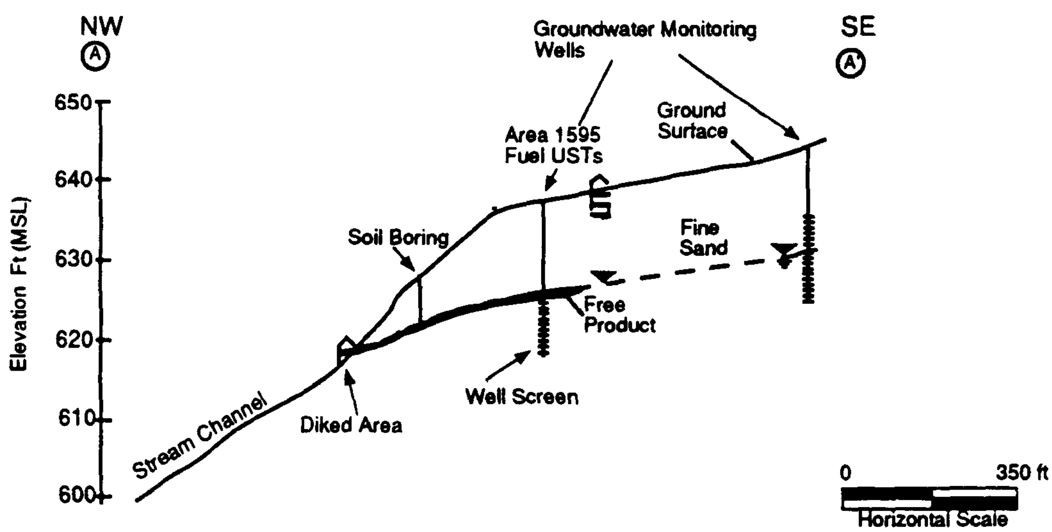
51 (1") Groundwater Concentration / Free Product Thickness, 2/90

BDL = Below Detection Limit

(-) indicates no free product measured



Profile A-A'



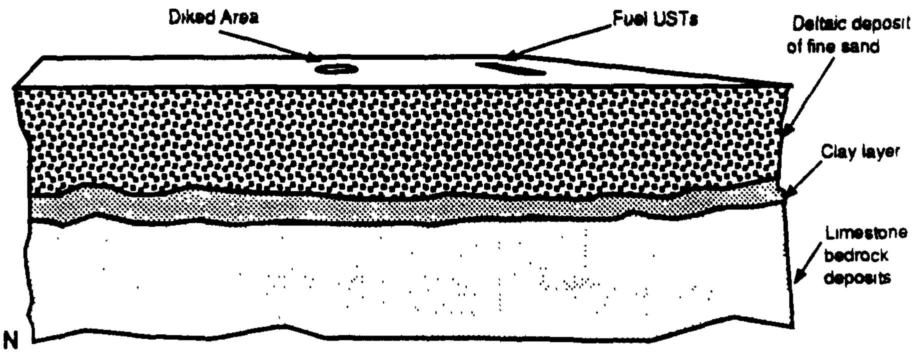
Vertical Exaggeration = 15X

Note: Extent of free product and soil and groundwater contamination not fully defined.

Contaminant Locations and Geologic Profiles (Continued)

Lithology of Area 1595

Conceptual Site Model: This model was constructed based on limited site geology information. The model is intended to provide a general pictorial representation of the site based on available information, but may not fully represent actual site conditions.



- The unconsolidated material observed in the study area is primarily fine-grained, well-sorted sand.
- The unsaturated zone ranges from approximately 6 to 15 feet below ground surface (BGS). It is thickest upgradient of the diked area (south). Groundwater is closest to the ground surface near the stream channel located downgradient of the diked area.
- Bedrock surface elevations at Area 1595 are unknown.

Site Conditions

- The regional average annual temperature is 45.1 °F. The regional monthly average rainfall is 3.28 inches. The monthly average snowfall is 9.51 inches.
- Ground surface elevations within Fort Drum range from approximately 450 to 900 feet above mean sea-level (MSL). The immediate vicinity of Area 1595 is relatively flat and is between 640 and 650 feet (MSL). The ground surface slopes toward the spring and diked area where it decreases to 610 to 620 feet (MSL). The surface elevation decreases from the diked area to approximately 510 feet (MSL) at the pond (approximately 3,000 feet away).
- Surface drainage from Area 1595 flows to the north, and into the unnamed stream, which leads to into Remington Pond.
- Groundwater flow direction within the unconsolidated deposits is primarily to the northwest, from the Area 1595 fuel dispensing area towards the spring and stream.
- The site is unpaved; infiltrating precipitation affects contaminants mobilization and migration.

Key Soil and Aquifer Characteristics

Groundwater Parameters

1993 pump test data, using 8 wells, unless noted:

Property	Range	Comment
Transmissivity	11,787 - 32,518	Jacob method
Storage coefficient	2.01 E -3 to 2.25 E -2	Jacob method
Groundwater velocity (ft/day)*	3.7	At location approximately 150 ft. northwest of fuel dispensing area
Hydraulic conductivity (cm/s)*	1.1 E -1 to 1.2 E -3	
Groundwater gradient (ft/foot)*	0.027	At location approximately 150 ft. northwest of fuel dispensing area
Percolation rate (in/yr)	15	Based on water balance

* Data is from a 1990 study of Area 1595.

Soil Parameters

Gasoline Alley data, not specific to Area 1595:

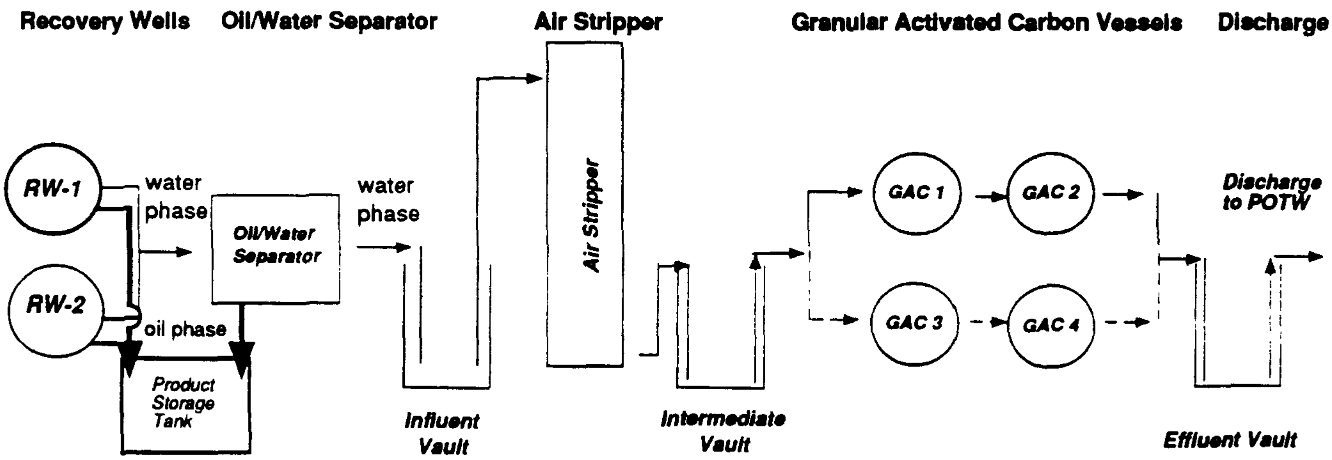
Property	Range
Sand Layer (19 borings)	
Moisture content	2.5 - 26.0
Plasticity index	characteristic not exhibited
Clay Layer (2 borings)	
Liquid limit(%)	22.2, 26.0
Plastic limit(%)	18.2, 19.1
Plasticity index	6.9, 8.3

- Twelve Fort Drum water supply wells and five residential supply wells are located within a one to four mile radius upgradient of Area 1595. Nine of the twelve wells, are completed in bedrock, and three are screened within the unconsolidated deposits.
- The primary source of groundwater for Fort Drum is a confined bedrock aquifer; the secondary source is a water table aquifer located within the unconsolidated deposits.

TREATMENT SYSTEM

The pump and treat recovery system operated from March 1992 to early/mid 1993, and was restarted in February 1994. During the first year of operation, efforts were focused on troubleshooting. Very little data was collected during this time period. Analytical data presented in this report was recorded during the most recent period (1994) of operation.

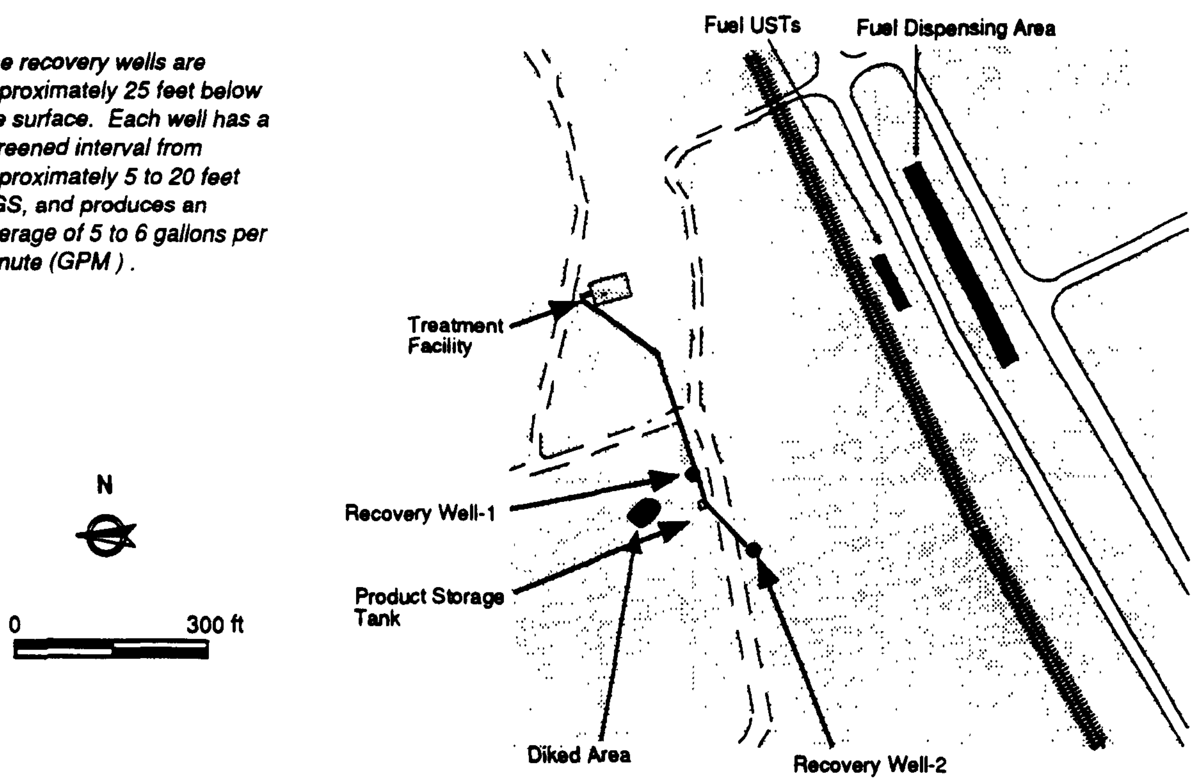
Overall Process Schematic



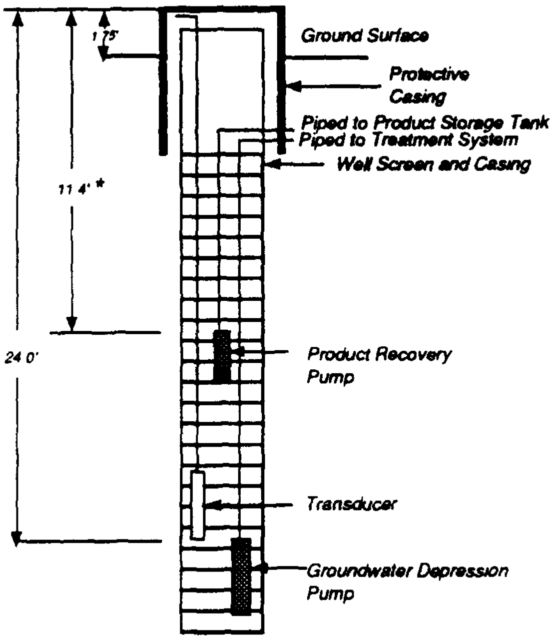
Free petroleum product accumulating in the recovery wells is pumped into a product storage tank. Water from the wells is pumped into the oil/water separator to remove residual free product and is treated by air stripping and granular activated carbon (GAC) to remove dissolved hydrocarbons. Treated water is then discharged to a publicly-owned treatment works (POTW).

Recovery Well Network

The recovery wells are approximately 25 feet below the surface. Each well has a screened interval from approximately 5 to 20 feet BGS, and produces an average of 5 to 6 gallons per minute (GPM).



Extraction Well Detail

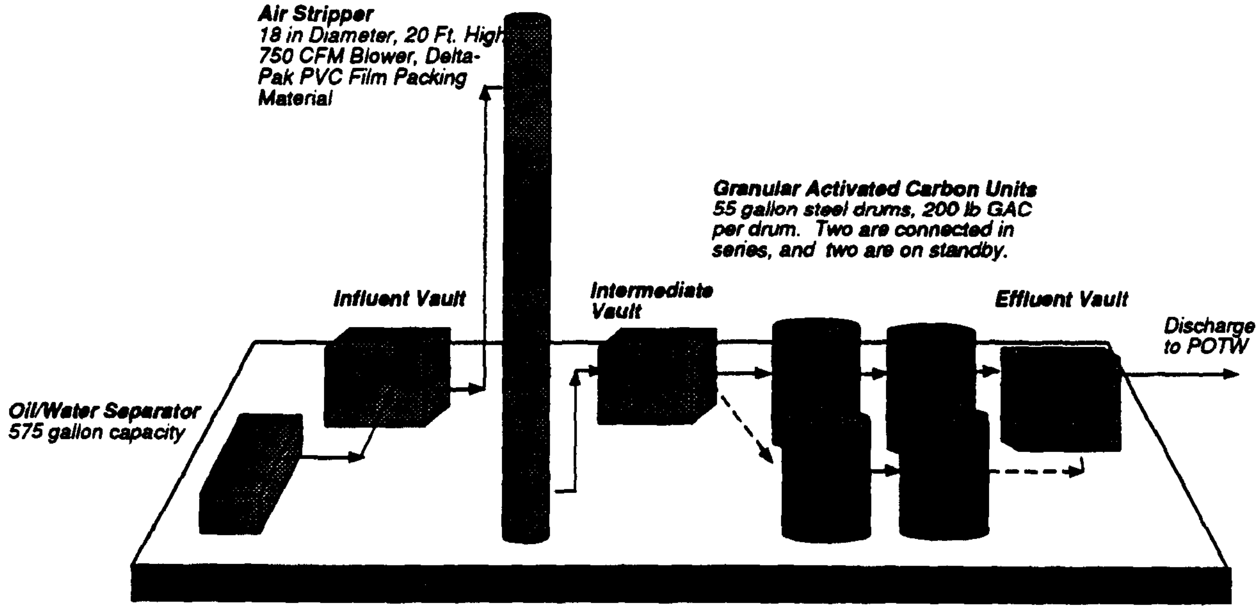


* Operator can manually adjust the elevation of the product recovery pump intake based on the observed floating product thickness and water level in the wells.

Key Monitored Operating Parameters

- Fluid levels in recovery wells
- Product storage tank volumes
- Influent flow rates
- Air stripper: Inlet flow rate and pressure, and blower pressure
- Granular activated carbon units: inlet flow rates and pressure
- Total effluent flow
- Contaminant concentrations in air stripper influent, air stripper effluent, and the GAC effluent

Air Stripping/Carbon Adsorption System Schematic



PERFORMANCE

Performance Objectives

- Recover free petroleum product from the water table as an interim measure.

Operational History

Initiated operations in March 1992. Operational difficulties prevented continuous operations.

↓

System shut down in early/mid 1993.

↓

Contractor retained to provide O&M and troubleshooting support. Reinitiated operations in February 1994.

Treatment Approach

Completed Activities

Preliminary assessment of the nature and extent of contamination through Initial Site Investigations

↓

Implementation of diked area skimming

↓

Design, construction, and operation of interim free product recovery (pump and treat) system

↓

Future Activities

Continue operating interim system to recover free floating petroleum product

↓

Conduct Phase II Remedial Investigation to fully define the extent of subsurface contamination associated with Gasoline Alley

↓

Develop and implement a comprehensive remediation program for Gasoline Alley (including Area 1595)

Operational/Treatment Performance

Free Product Recovery

Information on the total quantity of free product recovered and the rate of free product recovery over time was not available.

System Throughput

Information on the volumes of water treated was not available.

Influent Characteristics

Parameter	Concentration
Total hardness	120 mg/L
Total Alkalinity	121 mg/L
Iron	17.3 mg/L
Manganese	1.6 mg/L

System Downtime

The system did not operate continously during its periods of operation. The actual percentage of downtime is not known due to lack of operating records. The causes for the downtime are described below:

- The oil/water separator and the GAC units, fouled with inorganics and/or biomass.
- Seals in fuel recovery pumps deteriorated.
- Recovery well #2 was not recovering free product and was significantly contributing to the iron precipitation problem This well was shutdown sometime in 1993.
- The system was not operated and maintained by trained personnel, and the monitoring conducted was infrequent.

Skimming from Diked Area

Complete quantitative performance data on the effectiveness of efforts to skim free product from water collected in the diked area was not available.

Air Stripper and Activated Carbon Influent and Effluent

Insufficient data is available to determine if VOCs and target contaminants have been consistently treated below discharge levels. The data presented below represent analytical results for grab samples collected on February 11, 1994. This data represents the second treatment period.

Compound	Air Stripper Influent	Air Stripper Effluent /GAC Influent	GAC EFfluent
Benzene	86	2.5	<0.20
Toluene	130	4.3	<0.20
Ethylbenzene	120	2.9	<0.20
m-Xylene	320	9.7	<0.20
o-Xylene	86	3.8	<0.20
p-Xylene	<0.20	<0.20	<0.20

All concentrations in mg/L

Hydrodynamic Performance

The capture zone for the interim system has not been defined.

COST

Detailed cost data for the interim product recovery system construction and operation are not available. The cost breakdown below provides an estimate of costs for some components of the treatment system. Information was derived from projected costs, not actual cost data.

Capital Costs

System Design [a]	
Labor	$349,810
Direct Costs	12,420
Laboratory	3,490
Construction Costs [b]	
Site Work	102,350
Equipment	137,750
Mechanical	48,560
Structural and Architectural	121,770
Electrical	167,630
Mobilization/Demobilization	15,000
Total Capital Costs	$ 958,780

Operating Costs

Carbon Changeout, Transport, and Regeneration	$______
Electrical Power (@ $.___/kwh)	______
Equipment, Repair, and Replacement	______
Laboratory Analysis	______
O&M Labor (@ $____/hr)	______
Engineering Support	______
Project Management	______
Total Annual Operating Costs [c]	$129,440

[a] These costs were taken from a contractor's 95 percent design estimate prepared in 1991. They are included to provide a representation of the probable breakdown of actual total costs among the various cost elements.

[b] These figures are based on a contractors' cost proposal dated March 1991.

[c] Final operating costs are based on a contractor's scope of work for operation and maintenance of the interim pump and treat system, dated September 1993.

REGULATORY/INSTITUTIONAL ISSUES

• The Fort Drum Area 1595 site remediation is being performed as a Rapid Response Interim Remediation. Final cleanup criteria will be established for the site in the future.

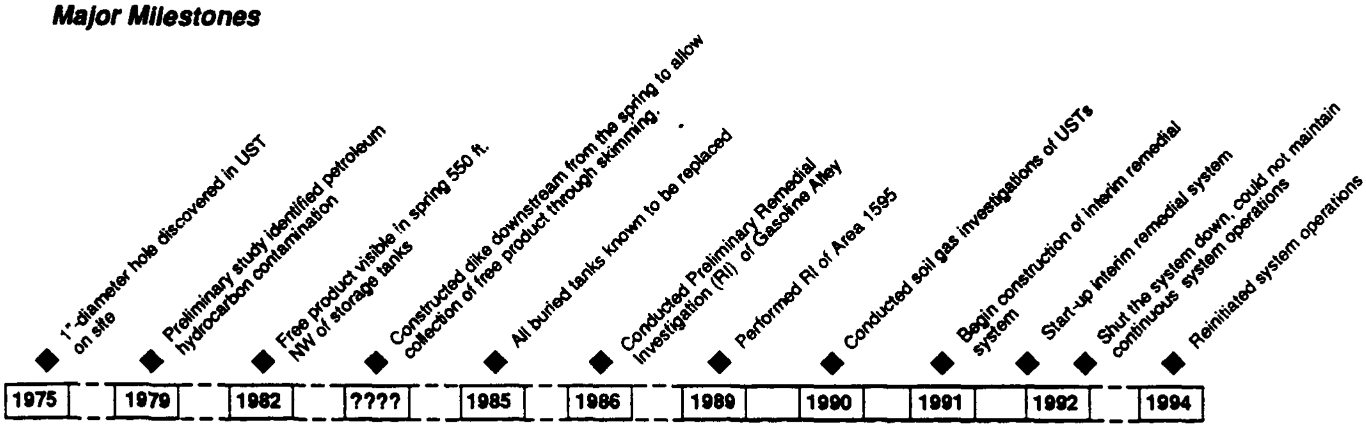
• Treated water is discharged under the authority of a POTW dishcharge interim permit. The permit was issued in December 1992. As an interim, the design effluent discharge limits for the air stripper are used. Discharge limits are summarized below:

Compound	Maximum Air Stripper Effluent Concentration (ug/l)
Benzene	3
Toluene	35
Xylenes	190
Ethylbenzene	8

• An air emission certificate was issued by the New York Department of Environmental Conservation in October 1992. Information on specific emission limits was not available.

SCHEDULE

Major Milestones



LESSONS LEARNED

Implementation Considerations

• Initiating an interim remedial action provided for recovery of free-phase petroleum product and petroleum constituents in groundwater while the full extent of contamination and supplemental remedial actions were planned. Earlier action could have further limited contaminant migration.

• The effectiveness of damming the dike to contain contamination was not addressed. During the winter of 1989, the surface of the diked area froze over. The skimming device froze below the ice, and free product migrated on top of the ice and past the dike. Free product was observed migrating below the absorbent pads.

• High iron concentrations (> 17 mg/L) were present in the Area 1595 groundwater. The presence of iron concentrations and potential precipitation problems should have been addressed in designing the interim system.

• The capture zone was not defined for the interim system. Consequently, the success or failure of the interim recovery system in capturing and limiting further migration of free product at this site is unknown. Defining the capture zone is an important part of evaluating the system's performance in capturing contaminants and stopping plume migration.

Technology Limitations

• The free product recovery pumps required frequent maintenance. Information was not available on whether alternative equipment would have been more appropriate.

• Activated carbon efficiency was limited in this instance by fouling caused by iron and/or biomass.

• No additional information was available on the full range of design and implementation experience gained from this technology application.

Future Technology Selection Considerations

• Application of the interim pump and treat system with above ground air stripping at Area 1595 of Fort Drum has not provided sufficient data to date to allow generalized conclusions to be made concerning the suitability of the technology at Fort Drum. Experience has been obtained, however, on design and implementation issues involved in assuring continuous system operation. Operational difficulties have only recently been overcome at Fort Drum and future performance data should provide a better understanding of the effectiveness of the interim product recovery system.

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

CERTIFICATION

The Fort Drum Environmental Division has indicated that, due to staffing limitations, they are unable to provide additional information necessary to complete this analysis or to review its contents.

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 1, 2, 3, 5, and personal communications with Brian Roberts of the U.S. Corps of Engineers (COE), Kansas City District.
Treatment System:	Source #s 4,5, and personal communications with Dan Gelb of Radian Corporation
Performance:	Source # 6, and personal communications with Dan Gelb and James Baxter of Radian Corporation
Cost:	Source # 6
Regulatory/Institutional Issues:	Source # 4
Schedule:	Source #s 1,2,3,6
Lessons Learned:	Source # 6, and personal communications with Dan Gelb and James Baxter of Radian Corporation

Chronological List of Sources and Additional References

1. Remedial Investigation Fuel Dispensing Area 1595 Fort Drum, New York; prepared for U.S. Army Corps of Engineers, Kansas City, Missouri (COE, Kansas City); prepared by O'Brien & Gere Engineers, Inc., February 1990.

2. Report of Findings - Corrective Measure Study Gasoline Alley, prepared for COE, Kansas City; prepared by CDM Federal Programs Corporation, September 1991.

3. Remdial Investigation of Fort Drum, New York, AMXTH-AS-CR-85054, prepared for U.S. Army Toxic and Hazardous Materials Agency (USATHAMA); prepared by Dames & Moore, August 1992..

4. Data Package provided by Dan Gelb of Radian Corporation, February 1994.

5. Area 1595 Map provided by James Baxter of Radian Corporation, April 1994.

6. Data Package provided by Brian Roberts of the US COE Kansas City District, April 1994.

Pump & Treat of Contaminated Groundwater at Langley Air Force Base Virginia (Interim Report)

Case Study Abstract

Pump & Treat of Contaminated Groundwater at Langley Air Force Base Virginia

Site Name:
Langley Air Force Base, IRP Site 4

Location:
Langley, Virginia

Contaminants:
Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) and Total Petroleum Hydrocarbons (TPH)
- Primary constituents of JP-4 fuel are alkanes, cycloalkanes, alkylbenzenes, indans/tetralins, naphthalenes
- Total Recoverable Petroleum Hydrocarbons - 25 to 4,100 ppb in groundwater; >100 ppm in soil
- Free product floating on groundwater has exceeded 1 ft. in thickness

Period of Operation:
Status: Ongoing
Report covers - 7/92 to 1/94

Cleanup Type:
Full-scale cleanup (interim results)

Vendor:
Not Available

SIC Code:
9711 (National Security)

Waste Source:
Underground Storage Tanks

Technology:
Groundwater Extraction using a Vacuum Assisted Well Point Extraction System and Aboveground Air Stripping
- Extraction - 16 vacuum extraction wells connected by a header pipe to a central vacuum system; wells extend to approximately 14 ft. below ground surface
- Extraction network has an average flow rate of 32 gpm (2 gpm per well); vacuum pump provides 24-25 in of Hg
- Separation - initial oil/water separation occurs in a vacuum decanter followed by a high efficiency oil/water separator; oil phase is sent to a storage tank
- Treatment of aqueous phase - 2 air stripping columns - Column 1 - air/water ratio of 180 and air flow of 1,440 cfm at 60 gpm; Column 2 - air/water ratio of 100 and air flow of 800 cfm at 60 gpm

Cleanup Authority:
UST Corrective Action and
State: Virginia

Point of Contact:
Vern Bartels
Remedial Project Manager
Langley AFB

Purpose/Significance of Application:
Full-scale remediation of groundwater contaminated with fuel oil using a vacuum assisted well point extraction system and aboveground air stripping.

Type/Quantity of Media Treated:
Groundwater and Free Product
- Area of free product - about 600 ft. x 300 ft.; estimated volume of free product is 12,000 to 31,000 gallons
- Area of groundwater contamination - about 1,000 ft. x 2,000 ft.
- Properties of aquifer include pH (6.4 - 7.2), hydraulic conductivity (0.00099 - 0.002 ft/day), transmissivity (0.99 - 2.2 ft^2/day)

Regulatory Requirements/Cleanup Goals:
- Groundwater: BTEX - Benzene (1.4 ppb), Toluene (2 ppb), Ethylbenzene (1 ppb), Total Xylenes (3 ppb)
- Air Stripper Criteria for discharge: BTEX - Benzene (7 ppb), Toluene (50 ppb), Ethylbenzene (4.3 ppb), Total Xylenes (13 ppb), Lead (5.6 ppb) and TPH (1,000 ppb)
- Cleanup conducted under Virginia State Regulations and Federal Underground Storage Tank Regulations

Pump & Treat of Contaminated Groundwater at Langley Air Force Base, Virginia (Continued)

Results:
As of 1/94:
- Floating product - appears to be largely unaffected at this time; no estimates of the amount of free product recovered are available at this time
- Air Stripper - average concentrations from air stripper are below discharge criteria

Cost Factors:
- Total Capital Costs - $569,739 (1992) (including demolition and excavation, system installation, startup, mobilization and site preparation)
- Annual Operating Costs - $216,561 (1993), $143,047 (1994) (including labor, materials, and equipment)
- An estimated total cost for completing the cleanup is not available at this time

Description:
Langley AFB has operated since 1916 as an aviation research and development facility. JP-4 fuel was stored in underground storage tanks and, in 1981, twenty-four 25,000-gallon underground fuel tanks and a fuel pipeline located at IRP Site 4 were determined to be leaking. In 1987, the tanks were abandoned by cleaning and sand-cement backfilling. Subsequent remedial investigation activities detected fuel contamination in soil and groundwater, including free product floating on the groundwater table at up to 1 foot in thickness. Primary contaminants of concern at the site are BTEX (benzene, toluene, ethylbenzene, and xylenes) and total petroleum hydrocarbons (TPH).

A groundwater pump and treat system consisting of a vacuum assisted well point extraction system, oil/water separators, and air strippers, began operating in July 1992 and was operational at the time of this report. Results to date indicate that, on average, the effluent concentration of BTEX, TRPH, and lead from the air stripper are below the discharge criteria. However, the layer of free product floating on the groundwater appears to be largely unaffected at this time. In addition, an estimate of free product recovered to date cannot be made since a sample port was not installed because of vacuum inlet conditions. It was noted that such sampling points are necessary to allow quantification of system performance.

The total capital costs for this application were about $569,700 and the annual operating costs for years 1993 and 1994 were about $216,600 and $143,000, respectively. Operational difficulties including problems with scaling, oil/water separator icing, and delays in acquiring spare parts have caused the system to be down about 51% of the time. In early 1994, adjustments to the system were made, including the use of chemical additives to prevent fouling of the system. It was noted that a roof over the treatment plant would have prevented weather-related damage and downtime (i.e., icing of oil/water separator).

TECHNOLOGY APPLICATION ANALYSIS

SITE

Langley Air Force Base
IRP Site 4
Langley AFB, Virginia

TECHNOLOGY APPLICATION

This analysis covers an effort to **pump and treat groundwater** contaminated with **JP-4 jet fuel** using a **vacuum assisted well point extraction system and above ground air stripping.** The treatment began in July 1992 and is currently ongoing. This analysis covers performance through January 1994.

SITE CHARACTERISTICS

Site History/Release Characteristics

- Langley AFB has been an aviation research and development establishment since 1916 and is the oldest continually active air force base in the U.S.

- IRP Site 4 contains twenty-four 25,000 gallon underground fuel tanks and a 6 inch JP-4 jet fuel pipeline. The tanks and pipeline were sources of leaks and were abandoned in 1987 by cleaning and sand-cement backfilling.

- Releases were first noted in 1981 and site characterization activities began in 1985. This technology application analysis presents data through January 1994 from ongoing treatment which began in July 1992.

Contaminants of Concern

The primary contaminant is JP-4 jet fuel whose principal constituents are:

Alkanes	61%
Cycloalkanes	29%
Alkylbenzenes	8%
Indans/tetralins	1.1%
Napthalenes	<1%

Indicator contaminants for the fuel mix are:

Benzene	(B)
Toluene	(T)
Ethylbenzene	(E)
Xylene	(X)

Site characterization also involved measurement of Total Recoverable Petroleum Hydrocarbons (TRPH) by EPA Method 418.1.

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Property at STP*	Units	JP-4**	B	T	X***
Empirical Formula	-		C_6H_6	$C_6H_5CH_3$	$C_6H_4(CH_3)_2$
Density	g/cm^3	0.75	0.87	0.86	~0.87
Vapor Pressure	mmHg	91	95	28	10
Henry's Law Constant	atm*m^3/mole	10E-4 to 10	5.6E-3	6.4E-3	7.0E-3
Water Solubility	mg/L	300	1750	535	198
Octanol-Water Partition Coefficient; K_{ow}	-	1E3 to 1E7	132	537	1830
Organic Carbon Partition Coefficient; K_{oc}	-	5E-6 to 240	83	300	240

**STP = Standard Temperature and Pressure; 1 atm, 25 °C*
*** Properties at 20°C ***Mixture of m,o and p-xylenes*

Nature & Extent of Contamination

- Fuels contamination is present in soil, as free product atop the groundwater table and dissolved in groundwater.

- Soil contamination appears to be limited to the area above the floating product and has exceeded 100 ppm TRPH in only one instance.

- Floating product has exceeded 1 foot in thickness in some locations. An oily sheen has been found in nearby estuaries.

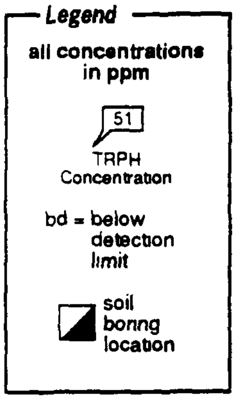
- Significant groundwater contamination (25 to 4100 ppb TRPH) appears to be limited to locations directly beneath areas having a thick floating product layer.

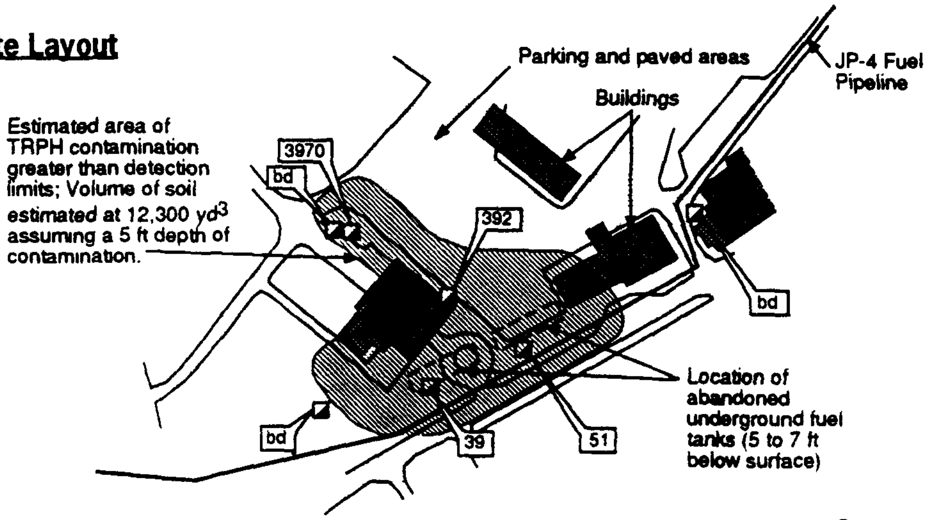
- The lack of a significant groundwater gradient has minimized the potential for migration, however, underground utilities and original fuel containment facilities may have created preferential pathways for transport.

Contaminant Locations and Geologic Profiles

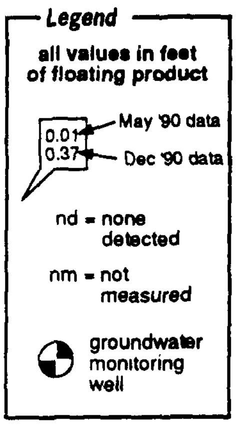
Remedial investigation field activities at the site have included soil and groundwater sampling and analysis, soil vapor analysis, geotechnical analyses and hydraulic conductivity measurements. Some of this data is included here to provide a general conceptual understanding of site conditions.

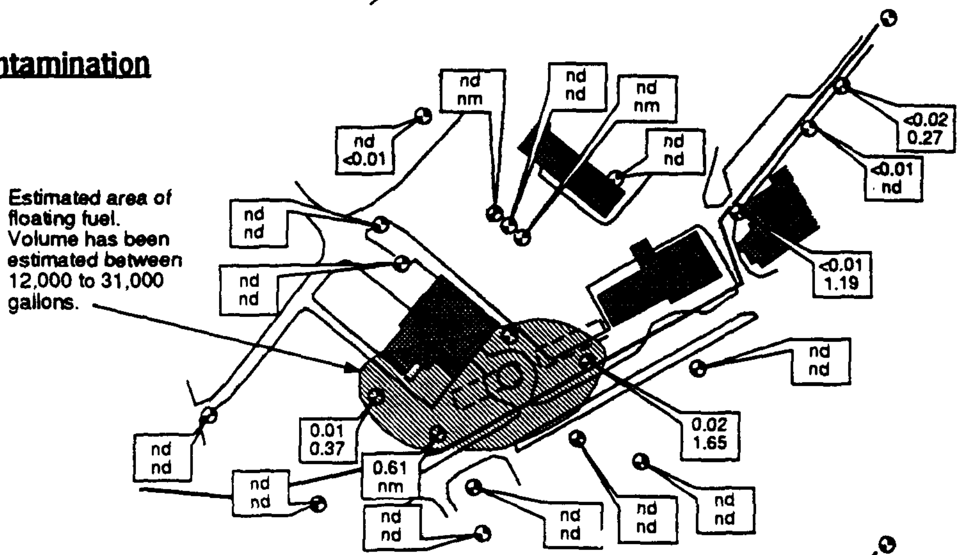
Soil Contamination & Site Layout



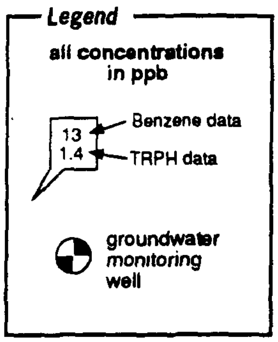


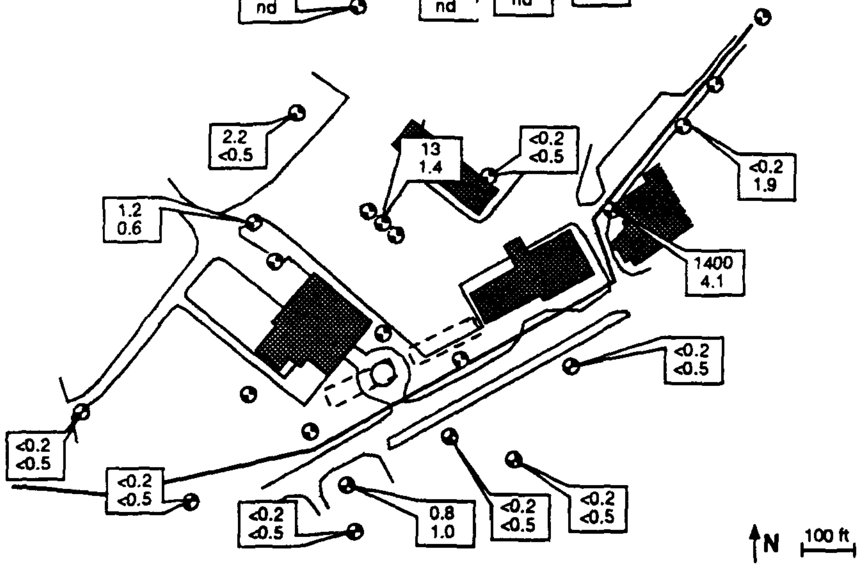
Floating Product Contamination





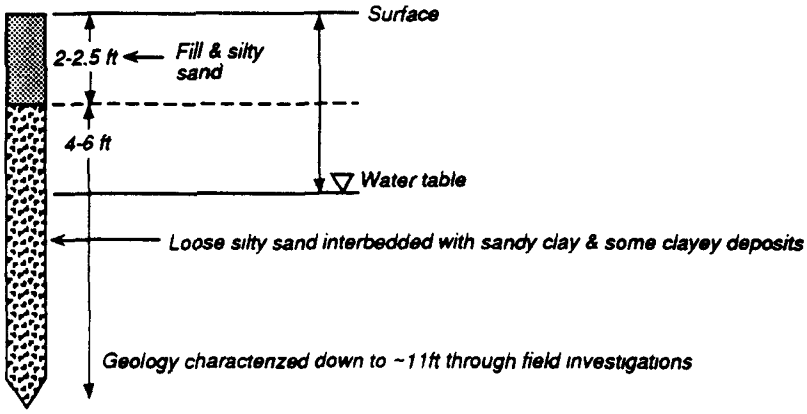
Groundwater Contamination





Contaminant Locations and Geologic Profiles (Continued)

Hydrogeologic Units



Site Conditions

- The topography of the base is very flat, showing little of no relief and ranging in elevation between 5 and 8 ft above MSL.
- Regional geology is that of an outer coastal plain characterized by a series of flat plains and intervening marine terraces.
- Land use in the nearby city of Hampton is primarily residential with 5% used by heavy or light industry. The base borders the highly environmentally sensitive Chesapeake Bay area.

Key Aquifer Characteristics

Soil Parameters ***(data taken from depths between 2 and 12 ft from six hand augered wells)***

Property	Range
Size distributions (% passing #200 sieve)	17-28%
Liquid limits	35-39%
Plasticity index	7-11%
Water content	23.8-36.2

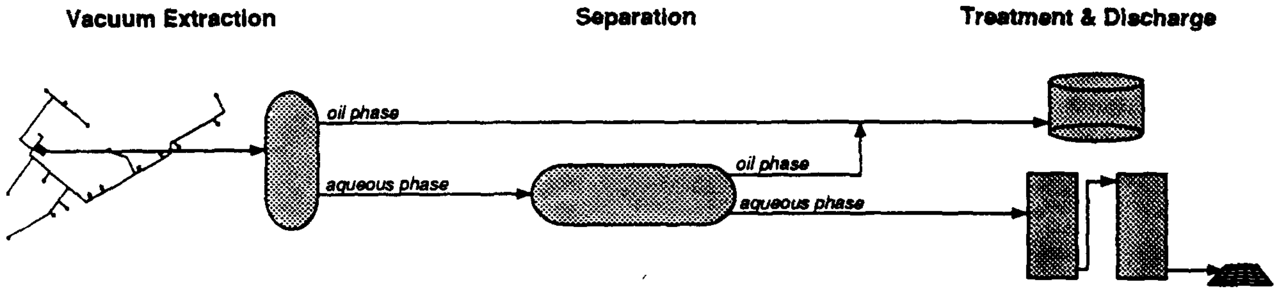
Groundwater Parameters ***(data taken during the development of six monitoring wells)***

Property	Range	Comment
Specific conductance	600-700 umhos/cm	
Temperature	20-24°C	
pH	6.4-7.2	
Hydraulic conductivity	0.00099-0.002	Based on slug in/slug out Bouwer & Rice method tests performed with two wells (slug out data shown).
Transmissivity	0.99-2.2	

- The groundwater occurs in three aquifer systems (water table, upper artesian and principal artesian) within the coastal plain sediments.
- The water table aquifer, beginning at 4-6 ft below the surface, occurs within the fine sand, silts and shell beds of Pleistocene age and surficial sands of recent Holocene age.
- The upper and principal artesian aquifers begin at depths of approximately 400 and 700 ft respectively. These aquifers are assumed to be free of contamination and are not considered further in this analysis.
- Due to high chloride concentrations from salt-water intrusion, none of the aquifers beneath the base are used for drinking water supply. The water table aquifer, however, is an important source of domestic water supply for locations west of the base.

TREATMENT SYSTEM

Overall Process Schematic

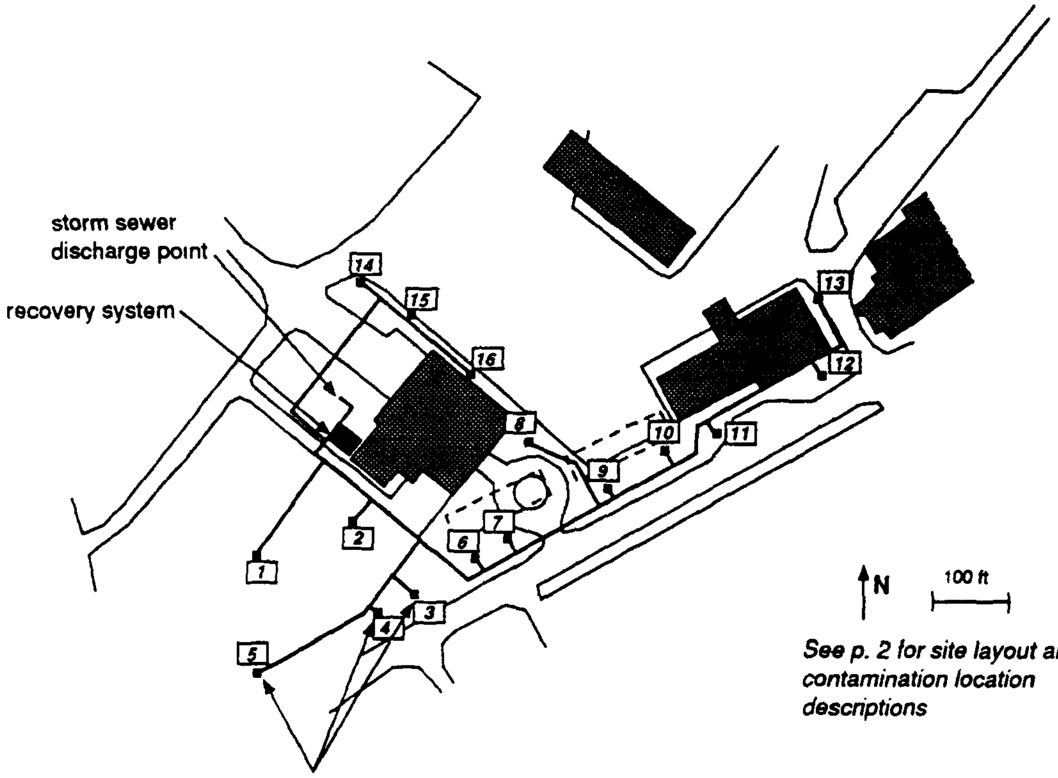


16 vacuum extraction wells are connected by a header pipe to a central vacuum system; initial separation occurs in a vacuum decanter [detailed below and on next page]

A high efficiency oil/water separator provides a second level of oil removal [detailed on next page]

- *Oil phase* - tank storage
- *Aqueous phase* - air stripping for a final level of VOC removal and permitted storm sewer discharge of treated effluent [detailed on next page]

Vacuum Extraction Well Network

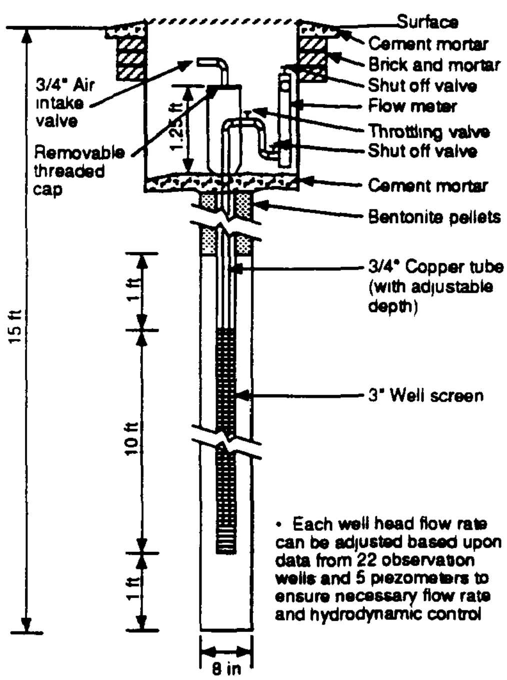


vacuum extraction wells; each of the 16 vacuum extraction wells extends approximately 14 ft below the surface and draws an average of 2 GPM

See p. 2 for site layout and contamination location descriptions

Extraction Well Close-Up

Typical Vacuum Extraction Well



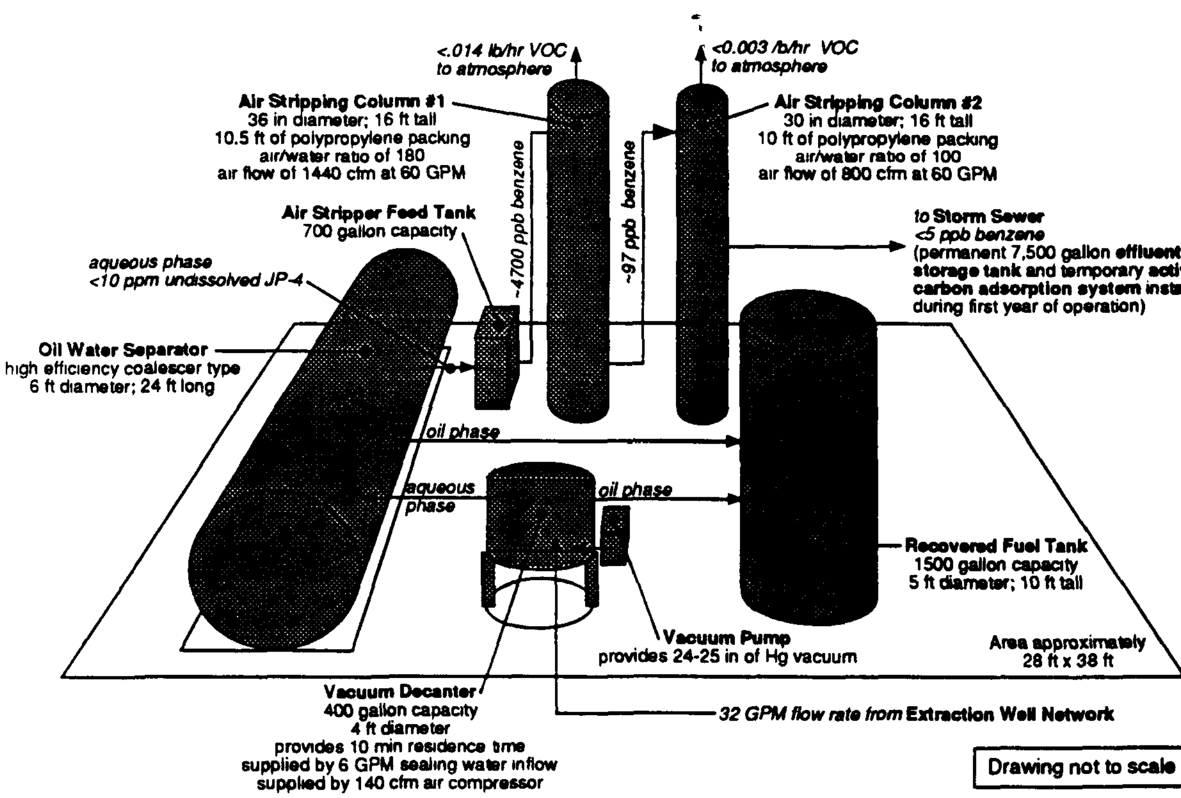
Key Design Criteria

- Maximum overlap of zones of influence of individual extraction wells within contaminated area
- Ability to create significantly increased oxygen levels in the vadose zone to enhance volatilization and biodegradation of residual soil contamination
- Ability to be installed without disturbing a complex network of existing underground utilities
- Treatment to satisfy Virginia Instream Values to allow for permitted storm sewer discharge (<5 ppb benzene from an influent of approximately 4700 ppb)
- Maximum flow of 60 GPM; Average flow of 32 GPM
- Series arrangement of air strippers for unobtrusive siting of treatment plant within air base facilities

Key Monitored Operating Parameters

- Extraction well flow rates
- Extraction well drawdown depths
- Monitoring well and piezometer location drawdown depths
- Flow to storm sewer
- Vacuum decanter vacuum pressure
- Recovered fuel tank level
- Contaminant concentrations in air stripper influent, air stripper effluent, between air stripper columns and in oil/water separator feed

Vacuum Extraction/Air Stripping Systems Schematic



PERFORMANCE

Performance Objectives

- Remove floating product atop groundwater to prevent further dissolution of contaminants (other criteria detailed in the Regulatory/Institutional section).
- Create a zone of capture that envelopes the floating product layer and prevents further migration.

Operational History

Initial operations in July 1992 resulted in discharge to the storm sewer of insufficiently treated contaminated groundwater. A notice of regulatory violation was imposed.

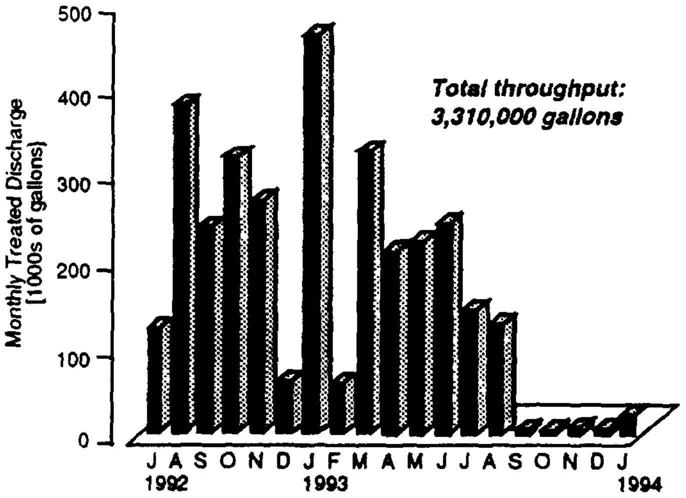
An effluent storage tank and carbon adsorption unit was procured to prevent future contaminated discharges.

Operational difficulties prevented sufficient continuous pumping to create an effective zone of capture. These difficulties are detailed below under System Downtime.

In early 1994, system adjustments permit continuous operation. These adjustments include the use of chemical additives to prevent system fouling. To date, performance data is insufficient to assess potential system effectiveness.

Operational Performance

System Throughput



System Downtime

During the period July 1992 through January 1994 the treatment system did not operate due to scheduled or forced downtime on **292 days (51% of all days).** Causes of downtime included:

- Scaling deposits destroyed impellers, couplings and connectors on pumps. Pipe diameters have been reduced from buildup of deposits. The system was flushed and cleaned to remove iron, calcium silicate and bacterial slime buildup. A chemical additive (Betz Ente-320) was applied to recovery wells and proved effective at preventing further fouling.
- Oil/water separator icing during shut downs.
- Delays in acquiring spare pumps.
- Regulatory requirements calling for sampling of recovery wells mandated system shut down and disassembly of well extraction equipment.

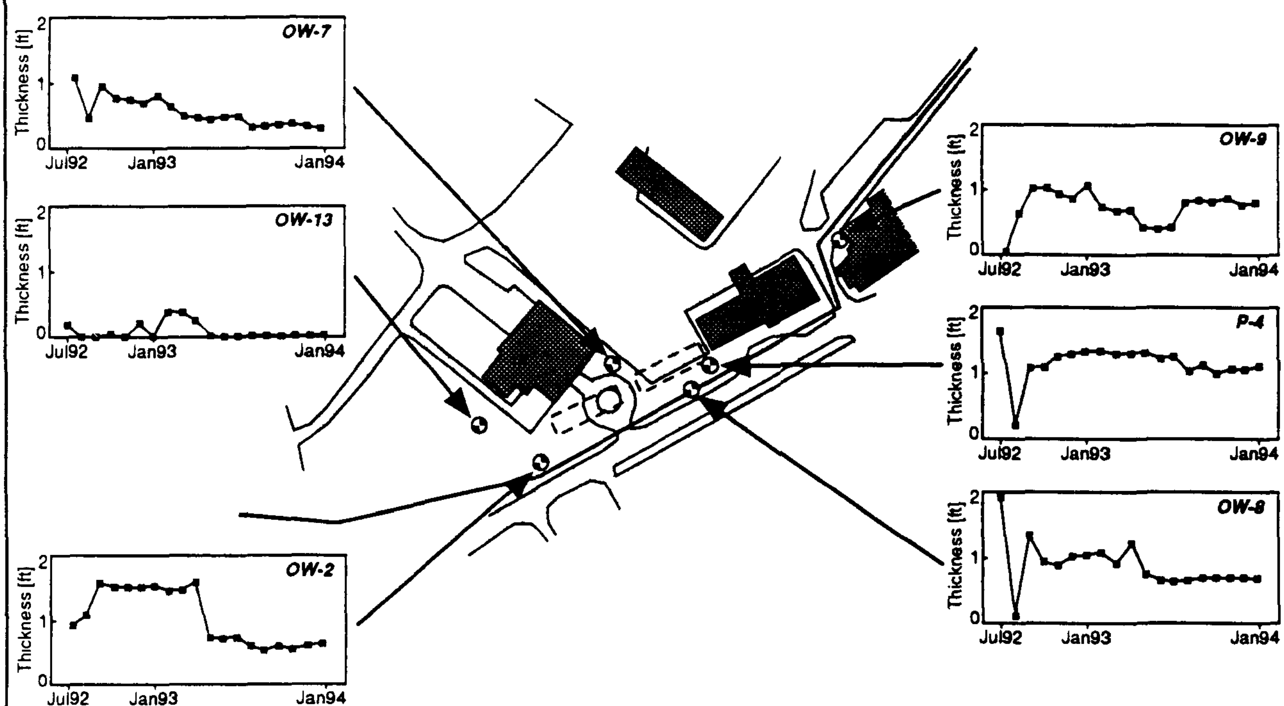
Hydrodynamic Performance

Quarterly prepared potentiometric maps of the surficial aquifer fail to indicate the influence of the treatment system to create a drawdown zone surrounding the contaminated region. Insufficient pumping duration appears to be the cause.

Treatment Performance

Effects on Floating Product Layer

Plots of floating product thickness over time at various wells containing the largest amount of fuel do not reveal overall trends. The floating layer appears largely unaffected to date.



Air Stripper Influent and Effluent

- All VOCs and targeted pollutants have been consistently treated below discharge criteria.

	Influent			Effluent		
Compound	Lo	Ave	Hi	Lo	Ave	Hi
Benzene	<5	<5	82	<5	<5	<5
Toluene	<5	<5	12	<5	<5	24
Ethylbenzene	<5	<5	150	<5	<5	<5
Xylenes	<5	<5	54	<5	<5	19
TRPH	-	-	-	<500	<500	1030
Lead	-	-	-	<1	<5	19

all concentrations in ppb

Free Product Recovered

- Currently there is no means to sample influent to the treatment system. No sample port was installed due to the vacuum inlet conditions.
- Negligible amounts of fuel have been observed in the recovered fuel tank.

COST

The U.S. Army Corps of Engineers Omaha District prepared a detailed cost estimate and specification for the treatment plant prior to procurement. That cost breakdown was pro-rated against the selected contractor's bottom-line price for system installation and start-up to arrive at the capital costs indicated below. Long-term operations and maintenance was procured via a lump-sum task order contracting mechanism. Initially estimated, contracted and final actual operating costs for the first few years of operation are presented below.

Capital Costs

Direct Costs	
Demolition & Excavation	$7,604
Horizontal Boring	5,661
Asphalt & Concrete	9,609
Screen Walls	33,560
Recovery Wells	49,403
Piezometers	8,674
Paint	593
Piping	54,537
Tanks/Equipment	111,961
Instrumentation	11,935
Electrical (Power, lighting and grounding)	24,377
Subtotal	317,914

Indirect Costs	
Mobilization & Site Preparation	21,748
Field Overhead	162,029
Other Overhead	34,048
Subtotal	217,826
Start-up (First 90 days O&M)	34,000
Total	**$569,739**

Operating Costs

	Year 1 (ending March 93)		Year 2 (ending March 94)		Year 3 (ending March 95)	
	Budget[a]	Actual	Budget[a]	Actual	Budget[a]	Actual
Labor	43,232	-	34,740	-	35,248	-
Materials	23,639	-	22,448		23,570	-
Equipment	38,535	-	2,268	-	2,365	-
Travel & Living Expenses	15,553	-	7,188	-	6,033	-
Overhead	46,916	-	34,881	-	34,965	-
Profit	9,851	-	7,339	-	7,452	-
Total	177,726	187,293[b]	108,864	112,112[b]	109,633	113,324[b]
Change Orders	0	29,268[c]	0	30,935[d]	0	Pending
Grand Total	**$177,726**	**$216,561**	**$108,864**	**$143,047**	**$109,633**	**Pending**

a - These initial budgeted amounts are taken from an Army Corps of Engineers estimate prepared in 1991 and are merely included to illustrate the probable breakdown of actual total costs among various cost elements.
b - The actual amounts are fixed priced task order sums taken agreed to by the O&M contractor
c - Necessary change orders in Year 1 included addition of an effluent storage tank and carbon adsorption unit to handle insufficiently treated flows during initial operation; system troubleshooting and optimization efforts; and laboratory analysis of effluent.
d - Necessary change orders in Year 2 included chemical flushing to remove iron, calcium and bacterial slime buildup throughout the system; analytical work; pump replacement; and oil water separator repairs.

REGULATORY/INSTITUTIONAL ISSUES

• The Corrective Action Plan was not approved by all necessary parties until well into the construction period of the system. Significant difficulties could have arisen if last minute objections were made.

• State approval of work plans significantly impacted the project schedule. Review periods over a year in duration occurred in some instances.

• To facilitate regulatory approval and maintain a project schedule, it was necessary to actively request face-to-face meetings to discuss work plans and treatment system design issues with approving agencies.

• Regulatory relief was successfully sought from the burden of sampling recovery wells in addition to monitoring wells and piezometers. Such sampling required dismantling and reassembly of recovery well apparatus.

• The treatment system was specially configured behind walls in a secure area to minimally impact operations and aesthetics at the active air base.

• Many specified materials were of foreign manufacture. Coordination with the Buy American Act was an issue.

• Cleanup was principally governed by Virginia State Regulations and Federal Underground Storage Tank Regulations 40CFR280.

Cleanup Criteria

• Concentrations of Total Petroleum Hydrocarbons in soil must be below 100 ppm in accordance with State of Virginia standards.

• Groundwater values must not rise above mean levels identified during site characterization efforts completed in 1991 of:

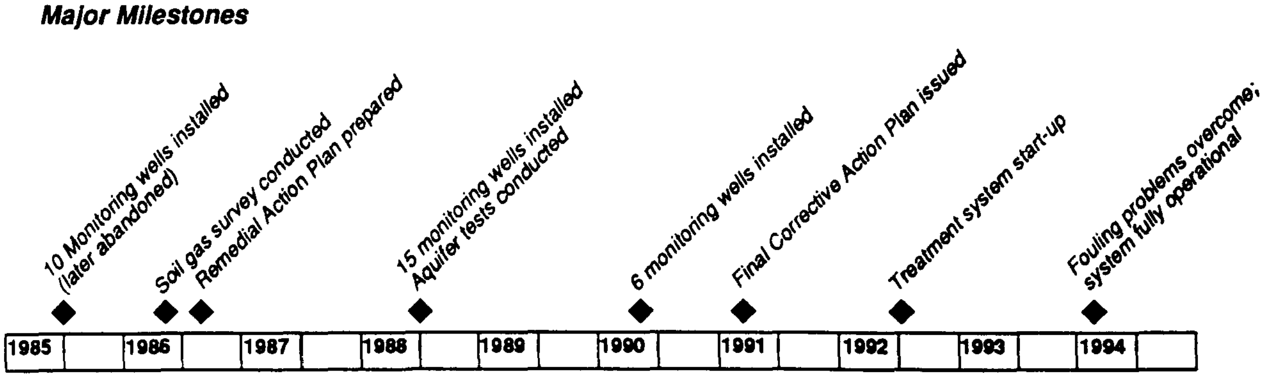
Compound	*Criteria Level [ppb]*	*Compound*	*Criteria Level [ppb]*
Benzene	1.4	Ethylbenzene	1
Toluene	2	Total Xylenes	3

• Virginia Instream Values were used as criteria for discharge of air stripper effluent:

Compound	*Criteria Level [ppb]*	*Compound*	*Criteria Level [ppb]*
Benzene	7	Total Xylenes	13
Toluene	50	Lead	5.6
Ethylbenzene	4.3	Petroleum Hydrocarbons	1000

SCHEDULE

Major Milestones



LESSONS LEARNED

Design Considerations

• Suction/vacuum pumps were designed to close to their limits at Langley to be dependable. These pumps experienced fouling and had to be replaced. Replacement parts were not readily available and spares should be specified for future systems.

• Heat tracing was inadequate and incomplete in the original design. The oil water separator experienced icing problems during periodic maintenance related shut downs.

• Sampling ports must be located at treatment plant influent to enable quantification of system performance.

• Controls must be readily accessible. At Langley, controls were located in a nearby secure area which made access more difficult.

• Operating contractor's offices must be adequately planned especially in instance where field analytical equipment requires special housing.

• The exhaust pipe on the oil water separator deflected excessively and allowed gases to be released. Adequate height and stability must be addressed in future designs for this element.

• A roof over the treatment plant would have prevented weather related damage and downtime.

• Recovery wells should be designed to allow cleaning and other maintenance without complete disassembly.

Implementation Considerations

• The Corrective Action Plan for the site must be approved by all necessary parties, in writing, in a timely manner before significant construction and design efforts are underway. Lengthy reviews of work plans impacted project schedules at Langley.

• Butt fusion welding proved to be highly expensive. An alternative method should be specified to address added connections or other system design changes in the field.

• Significant attention must be payed to early identification and prevention of conditions which may cause system fouling. Scaling of calcium silicate, iron and bacterial slime destroyed pump internals and reduced interior diameters of pipes. System flush outs and chemical additives to recovery wells were used to combat the problem.

• Recovery wells need to be periodically redeveloped.

Technology Limitations

• In this instance, a continuing series of operation problems prevented long term operation sufficient to create a zone of influence to capture and treat floating product atop the groundwater.

• Assessment of system performance was further complicated by inadequate ability to sample treatment plant influent.

Future Technology Selection Considerations

• Application of vacuum assisted pump and treat with above ground air stripping at Langley has not provided sufficient data to date to allow generalized conclusions to be made concerning the suitability of the technology at Langley or other potential locations. Much experienced has been obtained, however, on design and implementation issues involved in assuring continuous system operation. Operational difficulties have only recently been overcome at Langley and future performance data should provide a better understanding of its remediation effectiveness.

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental
Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

CERTIFICATION

This analysis accurately reflects the performance and costs of the remediation:

x Vern Bartels

Vern Bartels
Remedial Project Manager
Langley AFB

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 2, 3 and 6
Treatment System:	Source #s 1, 4, 5 and 7
Performance:	Source #s 1 and 2
Cost:	Source #s 1 and 3
Regulatory/Institutional Issues:	Source #s 1, 3 and 6
Schedule:	Source #s 1, 2, 3 and 6
Lessons Learned:	Source #s 1, 3 and personal communications with Eric Anthony Arndt, Deputy Area Engineer, Langley Resident Office, Norfolk District, Army Corps of Engineers (804) 764-2941

Chronological List of Sources and Additional References

1. Data package provided by Eric Anthony Arndt, Deputy Area Engineer, Langley Resident Office, Norfolk District, Army Corps of Engineers, March 28, 1994.

2. Data package provided by Eric Anthony Arndt, Deputy Area Engineer, Langley Resident Office, Norfolk District, Army Corps of Engineers, February 8, 1994.

3. Data package provided by S.L. Carlock, Chief, Environmental Branch, Engineering Division and Paul Dappen, Technical Manager, Army Corps of Engineers, Omaha District, November 16, 1993.

4. *Operations and Maintenance Manual (Pre-Final), for Installation Restoration Program - Site No. 4 Langley Air Force Base, Virginia*, prepared for U.S. Army Corps of Engineers, Omaha District, August 1991.

5. *Final Specifications, for Installation Restoration Program - Site No. 4 Langley Air Force Base, Virginia*, prepared for U.S. Army Corps of Engineers, Omaha District, August 1991.

6. *Final Corrective Action Plan for IRP Site 4, Langley Air Force Base, Virginia*, prepared by Law Environmental, prepared for U.S. Army Corps of Engineers, Omaha District, February 1991.

7. *Specifications (For Construction Contract) Solicitation No. DACA45 90 B 0088, Installation Restoration Work, IRP Site 4, Langley AFB, Virginia*, U.S. Army Corps of Engineers, Omaha District, July 1990.

Dynamic Underground Stripping Demonstrated at Lawrence Livermore National Laboratory Gasoline Spill Site, Livermore, California

Case Study Abstract

Dynamic Underground Stripping Demonstrated at Lawrence Livermore National Laboratory Gasoline Spill Site, Livermore, California

Site Name: Lawrence Livermore National Laboratory, Gasoline Spill Site **Location:** Livermore, California	**Contaminants:** Benzene, Toluene, Ethylbenzene, Total Xylenes (BTEX) - Concentrations of fuel hydrocarbons (FHC) in saturated sediments indicates likely presence of free-phase gasoline - Benzene levels in groundwater greater than 1 ppb found within 300 feet of release point - Benzene levels in soil greater than 50 ppm	**Period of Operation:** November 1992 - December 1993 **Cleanup Type:** Field demonstration (commercial-scale)
Technical Information: Roger Aines, Principal Investigator, LLNL (510) 423-7184 Robin Newmark, LLNL (510) 423-3644 Kent Udell, UC Berkeley (510) 642-2928 **SIC Code:** 5541 (Gasoline service station) **Waste Source:** Underground Storage Tanks	**Technology:** Dynamic Underground Stripping (DUS) - Combination of three technologies: steam injection at periphery of contaminated area to drive contaminants to centrally-located vacuum extraction locations; electrical heating of less permeable soils; and underground imaging to delineate heated areas - Six steam injection/electrical heating wells approximately 145 feet deep, 4-inch diameter, screened in upper and lower steam zones - Three electrical heating wells approximately 120 feet deep, 2-inch diameter - Three groundwater and vapor extraction wells, approximately 155 feet deep, 8-inch diameter - Extracted water processed through an air-cooled heat exchanger, oil/water separators, filters, UV/H_2O_2 treatment unit, air stripping, and GAC - Extracted vapors processed through heat exchanger, demister, and internal combustion (IC) engines	**Cleanup Authority:** CERCLA and Other: Bay Area Air Quality Management District **Licensing Information:** Kathy Willis University of California Office of Tech Transfer 1320 Harbor Bay Parkway, Suite 150 Alameda, CA 94501 (510) 748-6595 Kathy Kaufman Tech. Transfer Init. Program, L-795 University of California Lawrence Livermore Nat'l. Laboratory 7000 East Avenue P.O. Box 808 Livermore, CA 94550 (510) 422-2646

Purpose/Significance of Application:
Commercial-scale demonstration of dynamic underground stripping. Results compared to pump and treat, and pump and treat with vacuum extraction technologies.

Case Study Abstract

Dynamic Underground Stripping Demonstrated at Lawrence Livermore National Laboratory Gasoline Spill Site, Livermore, California (Continued)

Type/Quantity of Media Treated:
Soil and Groundwater
- 100,000 cubic yards heated to at least 200°F
- 4 hydrogeologic units and 7 hydrostratigraphic layers identified near gas pad
- Hydraulic conductivity ranged from <5 gpd/ft^2 (low permeability) to 1,070 gpd/ft^2 (very high to high permeability)
- Low groundwater velocities kept contamination confined to a relatively small area

Regulatory Requirements/Cleanup Goals:
- Groundwater cleanup levels established based on California MCLs: benzene 1 ppb; ethylbenzene 680 ppb; and xylenes 1,750 ppb
- Remediation was required until soil contaminant concentrations were identified as not adversely impacting groundwater
- Air permits were issued by the BAAQMD for the air stripper, GAC, IC engine, and for site-wide benzene

Results:
- Over 7,600 gallons of gasoline removed during demonstration effort
- Most of the gasoline was recovered in the vapor stream and not from extracted groundwater

Cost Factors:
- Overall program costs for the field demonstration, including all research and development costs, were $1,700,000 for before-treatment costs (project management, characterization and compliance monitoring), and $8,740,000 for treatment activities (process monitoring, subsurface wells, steam generation and electrical heating surface equipment, aboveground treatment systems, utilities, and labor and material costs)

Description:
The 800-acre Lawrence Livermore National Laboratory (LLNL) site was used as a flight training base and aircraft assembly and repair facility by the Navy beginning in 1942. In 1951, the Atomic Energy Commission converted the site into a weapons design and basic physics research laboratory. Initial releases of hazardous materials occurred in the mid- to late-1940s. Between 1952 and 1979, up to 17,000 gallons of leaded gasoline were released from underground storage tanks beneath a gasoline filling station in an area now designated as the Gasoline Spill Area (GSA). Soil and groundwater in the GSA were found to be contaminated with BTEX (benzene, toluene, ethylbenzene, and xylenes) and fuel hydrocarbons.

A commercial-scale field demonstration of Dynamic Underground Stripping (DUS) was completed at the GSA from November 1992 to December 1993. DUS is a combination of three technologies: steam injection at the periphery of a contaminated area to drive contaminants to a centrally-located vacuum extraction location; electrical heating of less permeable soils; and underground imaging (primarily Electrical Resistance Tomography) to delineate heated areas. The DUS system used at the GSA employed 6 steam injection/electrical heating wells, 3 electrical heating wells, and 3 vacuum extraction wells, as well as above ground water and vapor treatment equipment.

Over 7,600 gallons of gasoline were removed by the DUS system in the demonstration effort. Most of the gasoline was recovered in the vapor stream and not from the extracted groundwater. Potential cost savings of $4,000,000 were identified for applying DUS at the same site in the future (taking into account the benefits of the lessons learned and without research-oriented activities).

SECTION 1

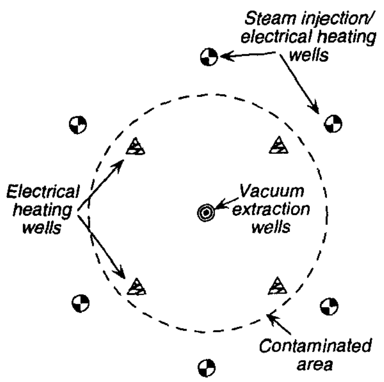
SUMMARY

1

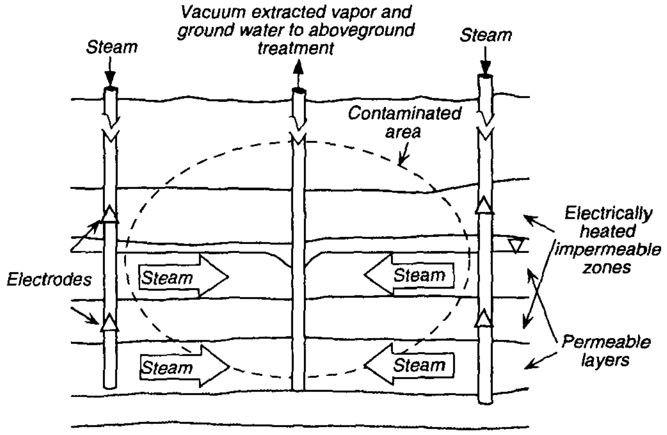
Technology Description

Dynamic Underground Stripping (DUS) is a combination of several technologies targeted to remediate soil and ground water contaminated with organic compounds. DUS is effective both above and below the water table and is especially well suited for sites with interbedded sand and clay layers. The main technologies which comprise DUS are:

- ***steam injection*** at the periphery of a contaminated area to heat permeable subsurface areas, vaporize volatile compounds bound to the soil, and drive contaminants to centrally located ***vacuum extraction*** wells;
- ***electrical heating*** of less permeable clays and fine-grained sediments to vaporize contaminants and drive them into the steam zone; and
- ***underground imaging***, primarily Electrical Resistance Tomography (ERT), which delineates heated areas to ensure total cleanup and process control.



Plan View



Cross-Sectional View

Technology Status

A full-scale demonstration was conducted at:
Lawrence Livermore
National Laboratory (LLNL)
Gasoline Spill Site: GSA
Livermore, California
November 1992 through December 1993

Before application of DUS, the site contained an estimated 6,500 gallons of fuel hydrocarbons (FHCs) both above and below the water table at depths up to 150 ft. The site is underlain by complexly interbedded high and low permeability sediments.

Key results included:

- The system removed over 7,000 gallons of gasoline (more than the original estimate of contamination) during 10 weeks of operation conducted in phases over a 1-year period. The maximum extraction rate was 250 gallons per day.
- DUS removed the localized underground spill at LLNL more rapidly and cost-effectively than the estimated effectiveness of competing baseline technologies of pump-and-treat or pump-and-treat with vacuum extraction.
- DUS is projected to cost between $11 and $37 per cu yd of contaminated soil and is projected to remediate a site in six to nine months as opposed to thirty years for the baseline technology of pump and treat.

Technology Status (continued)

Over a dozen patents covering the major aspects of DUS are either pending or have already been granted to DOE and the University of California. DUS is licensable from the University of California Office of Technology Transfer, and licensing discussions are currently in progress. The results of the LLNL demonstration illustrating the effectiveness of subsurface heating are corroborated by the results of field-scale demonstrations of other in situ thermal treatment processes conducted through other EPA, DOD, and DOE programs. Conceptual designs, cost estimates, and detailed designs have been prepared for applying DUS at other sites. Future development efforts will focus upon applying the technology at sites contaminated with dense nonaqueous phase liquids (DNAPLs) and at sites with fractured subsurface media.

Contacts

Technical

Roger Aines, Principal Investigator, LLNL, (510) 423-7184

Robin Newmark, LLNL, (510) 423-3644

Kent Udell, UC Berkeley, (510) 642-2928

Management

John Mathur, DOE Program Manager, (301) 903-7922

Jim Wright, DOE Plumes Focus Area Implementation Team Manager, (803) 725-7289

Licensing Information

Kathy Kaufman, Technology Transfer Initiative Program, Lawrence Livermore National Laboratory, (510) 422-2646

Kathy Willis, University of California Office of Tech Transfer, (510) 748-6595

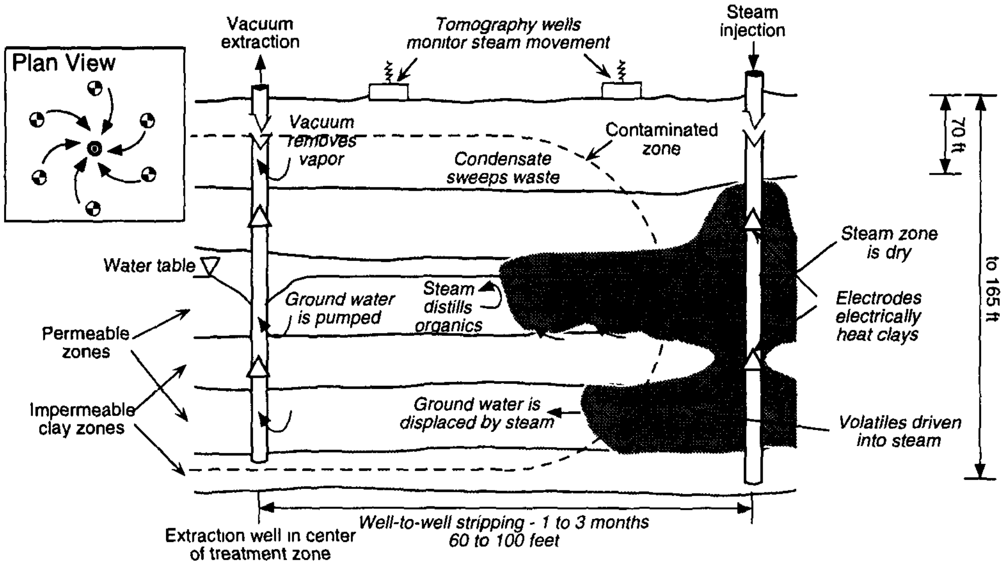
SECTION 2

TECHNOLOGY DESCRIPTION

2

Overall Process Schematic

DUS combines steam injection, electrical resistance heating, and underground imaging and monitoring techniques to mobilize and recover contaminants from the subsurface. The figure below is a conceptual illustration of the process for relatively simple subsurface conditions. Appendix B provides detailed information about the process including close-ups of subsurface wells and descriptions of surface treatment equipment.



Major elements of the technology are:

Steam Injection and Vacuum Extraction - Injection wells drilled around an area of concentrated contamination supply steam and electric current. Vacuum extraction wells in the center of the contaminated area remove contaminants. A steam front develops in the subsurface as permeable soils are heated to the boiling point of water and volatile organic contaminants are vaporized from the hot soil. The steam moves from the injection to the extraction wells.

Electrical Resistance Heating - Electric current is used to heat impermeable soils. Water and contaminants trapped in these relatively conductive regions are vaporized and forced into the steam zone for vacuum extraction.

Underground Imaging and Monitoring - Several geophysical techniques used to monitor the underground movement of steam and the progress of heating include temperature measurements (taken from monitoring wells throughout the treatment area), ERT (which relates measurement of electrical conductivity to the progress of the steam front in the heated zone, and tiltmeters (which detect small subsurface pressure changes created by the movement of the steam front).

Generalized Treatment Plan

A generalized approach to implementing DUS developed as a result of the demonstration includes:

Electrically heat impermeable clay zones

↓

Inject steam into peripheral wells; extract ground water and vapor from central wells

↓

- Prepare plots of subsurface steam influence from ERT, piezometer, and tiltmeter data
- Monitor in situ ground water contaminant levels
- Monitor subsurface temperatures from thermocouple data
- Monitor aboveground flow, concentration and temperature data

↓

Adjust flow rates to optimized growth of steam fronts

↓

Operate steam intermittently to flash off contaminants in pore spaces

↓

Operate until rate of contaminant removal diminishes significantly or cleanup objectives are satisfied

Demonstration Operations and Results Overview

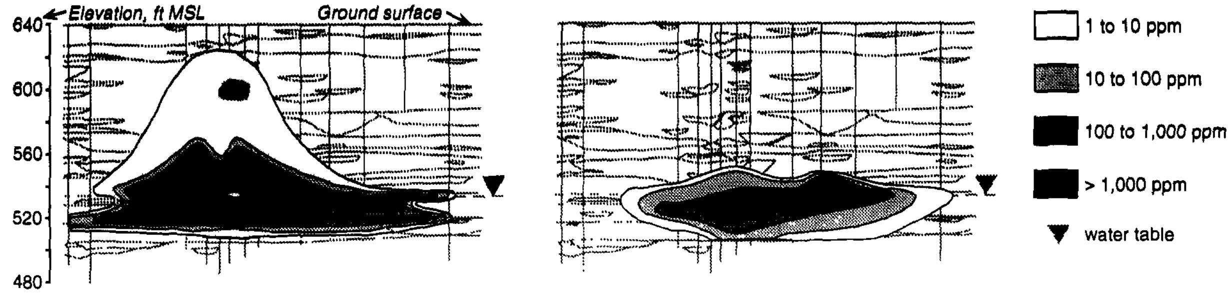
DUS activities at LLNL occurred in a series of demonstration efforts:

PHASE	OBJECTIVES/APPROACH	KEY RESULTS
Clean Site Demonstration	To field test the DUS process on an uncontaminated site with well-characterized geology	Steam injections, electric heating, and monitoring well design improvements were identified Identification of improved operating strategy of electric heating before steaming
DUS Demonstration *Electrical Heating Phase*	To heat less permeable contaminated clay zones	Temperature of clay layers raised from 70°F to 160°F
DUS Demonstration *1st Pass Steaming Phase*	Continuous steam injection over a 5-week period to vaporize and remove gasoline	Over 1700 gal of gasoline removed
DUS Demonstration *2nd Pass Steaming Phase*	Intermittent steam injection and vacuum extraction over a 6-week period	Over 4900 gal of gasoline removed Temperature of most soils within treatment zone exceeds 212°F; residual contamination (estimated at 750 gal) and an unsteamed area ("cold spot") remained
Accelerated Removal & Validation (ARV) Project	Continuous operation to remove residual contamination; additional electrical heating	Over 1000 gal of gasoline removed Improved understanding of electrical heating process developed
	Test of process modifications such as altering injection/extraction locations and air sparging	Sparging tests demonstrated value of modeling and use of tracer gases to better understand subsurface gas flow
	Installation of fiber-optic transmission system to allow for simultaneous electrical heating and process monitoring	Fiber-optics successfully installed

Treatment Performance

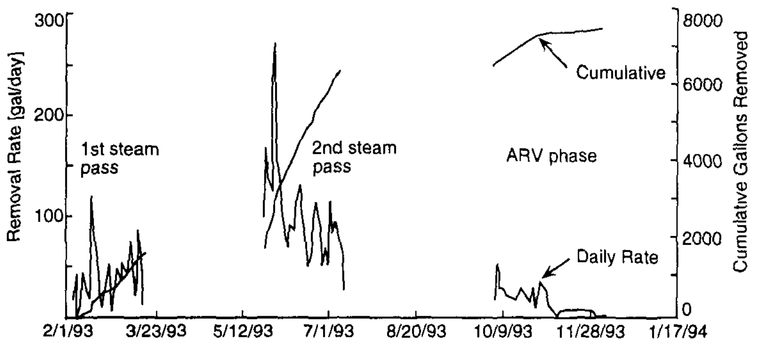
Reductions in Plume Concentrations

Estimated Total Fuel Hydrocarbon concentrations before and after the second steam pass of DUS are shown below:



- No spreading observed; contamination drawn to extraction wells.
- Continued operation during the ARV phase removed an additional 1000 gallons.
- The ability of DUS to remove contaminants sorbed to soils was illustrated by a marked rise in benzene and total gasoline concentrations in ground water during DUS. At one ground water monitoring well in the treatment zone, concentrations of C6 to C12 hydrocarbons had been below 30 ppm since 1987, but during DUS these concentrations rose to nearly 150 ppm before dropping to levels below those found before DUS.

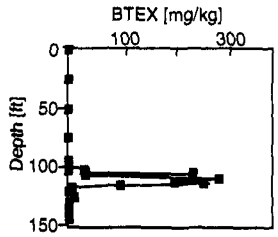
Contaminant Mass Removal



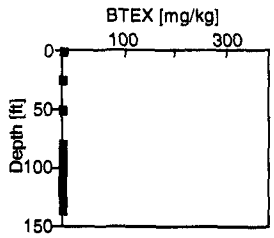
- During the DUS 1st steam pass, 74% of approximately 1700 gallons removed was collected by the vapor stream GAC unit. An additional 17% condensed in the vapor stream and the remaining 9% was dissolved in ground water.
- During the 2nd steam pass, 77% of the 4900 gallons removed was burned by the internal combustion engines, 21% was condensed, and 1% was dissolved.

Plume Containment

- The GSA was an ideal spot for demonstration of DUS because of its low ground water velocities, which kept contamination confined to a relatively small area. The plots at right illustrate that BTEX concentrations in soils at the periphery of the treatment zone declined during the demonstration. This phenomenon was determined to be indicative of the DUS process limiting further migration of contamination.



Before DUS at a typical well at the edge of the treatment zone



After 2nd steam pass of DUS at the same well

3

Operational Performance

Aboveground Treatment Plan Performance

- The majority of contaminants removed from the subsurface was in the vapor phase.
- Surface treatment consisted of (1) a UV/peroxide unit to treat ground water and condensed vapors during both phases of the demonstration, (2) a GAC unit to treat vapors removed during phase I, and (3) an ICE unit to treat the vapors removed during phase II.
- The volume of contaminated vapors removed from the subsurface was initially underestimated. Thus the GAC unit selected for offgas treatment was undersized. It was replaced by an ICE unit during phase II. The ICE unit could also have been larger but nevertheless performed successfully. Dilution of air was necessary since the hydrocarbon concentrations were above the explosive limit.
- Destruction efficiencies of the UV peroxide liquid treatment unit during the last half of the first steam pass were less than 40%, but adjustments maintained an efficiency over 90% during the last half of the second steam pass.
- Free gasoline product was found in the UV peroxide unit after the first steam pass.

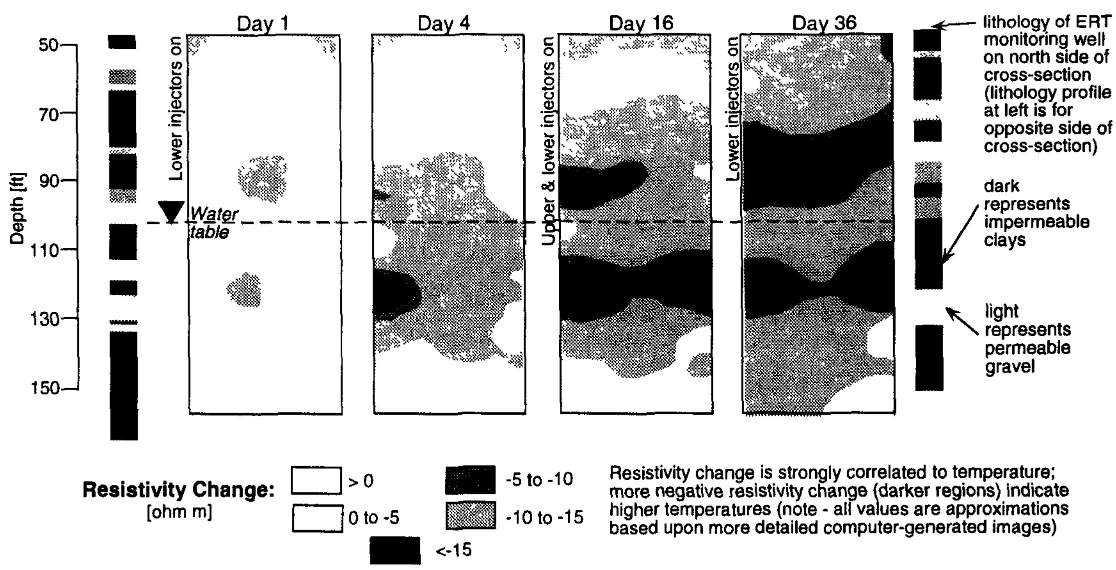
* *GAC = granular activated carbon; ICE = internal combustion engine*

In Situ Heating Performance

- A total of 100,000 yd^3 of soil were heated at least to 200°F (boiling point at applied vacuum).
- The growth of the hot zone was monitored by ERT and a network of temperature probes and tiltmeters.
- A variety of data was used to prepare multiple representations of heating effects:

Electrical Resistance Tomography Imaging

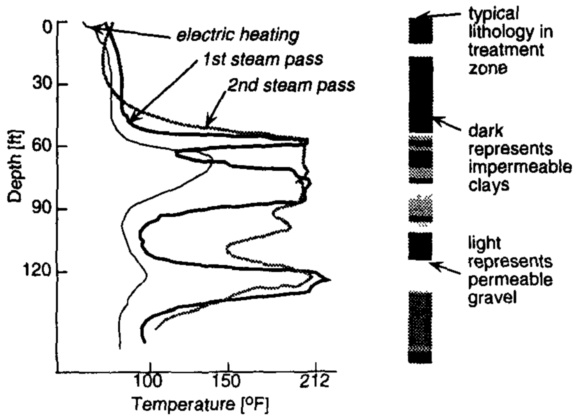
Below are images illustrating resistivity change over time between two monitoring wells approximately 50 ft apart in the central part of the treatment zone.



- ERT images provide a continuous representation of steam passage between two electrode-equipped boreholes.
- The process allows identification of "cold spots" and provides data to support efforts to provide uniform heating.

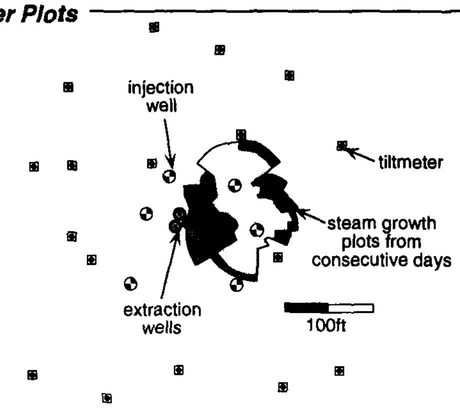
In Situ Heating Performance (continued)

Temperature Profiles Along Individual Wells



- More permeable layers heat first.
- Heating ultimately effective throughout treatment zone.

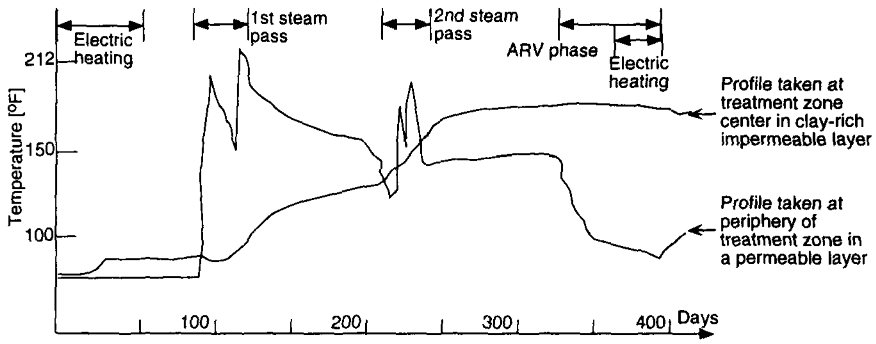
Tiltmeter Plots



- Tiltmeter data allow generation of vector-based representations of steam front growth on a given day from two injection wells.
- Data are useful for tracking any steam heading outside the treatment zone.

Time Versus Temperature Plot

- Impermeable layers maintained temperature increases.
- Permeable layers were cooled by ground water pumping especially at peripheral wells because of infiltration of ground water from outside the treatment zone.



3

SECTION 4

TECHNOLOGY APPLICABILITY & ALTERNATIVES

Technology Applicability

• DUS has been successfully demonstrated to remediate fuel hydrocarbons. Laboratory tests have been successful for a variety of volatile and semivolatile compounds including diesel fuel and both light nonaqeuous phase liquids (LNAPLs) and dense nonaqueous phase liquids (DNAPLs).

• DUS is effective in the presence of free-phase and dissolved-phase contaminant liquids. It is extremely effective in the absence of liquids (vadose zone) but is usually not cost effective versus alternative technologies in these instances. It would be better applied at sites with contamination both above and below the water table.

• The minimum depth for application of DUS is approximately 5 feet. At greater depths, the steam injection pressure can be increased, producing higher efficiencies and extracting more work from each well.

• DUS becomes more cost-effective the larger the application site.

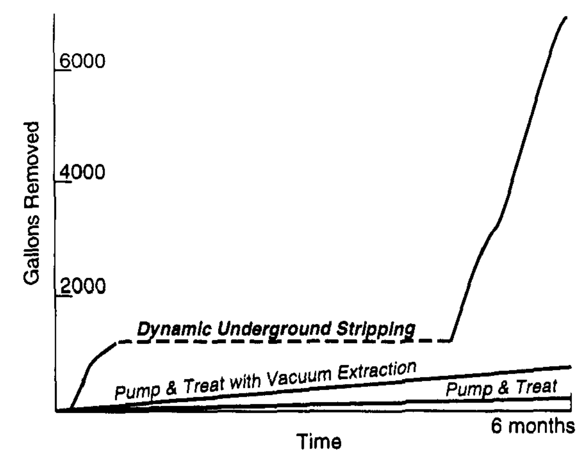
• A key competitive advantage of DUS is the speed of cleanup relative to conventional technologies. This order-of-magnitude superiority reduces overall cost, reduces risk to nearby populations and the environment, and frees land for beneficial reuse.

• DUS has a potential market at sites where conventional technologies have failed to produce acceptable results. The GSA site at LLNL is an example; soil vapor extraction had been previously applied and its performance predicted a cleanup time of greater than one hundred years.

• DUS is best suited to treat NAPLs and strongly sorbed contaminants in heterogenous or fractured formations. Unlike most competing technologies, it can directly address contamination in complexly interbedded sands and clays. Further information on the applicability of DUS is in Appendix D.

Competing Technologies

• DUS competes with conventional baseline technologies of pump-and-treat and pump-and-treat combined with soil vapor extraction. LLNL researchers estimated the effectiveness of these technologies at the GSA and compared the estimates with the results of the DUS demonstration, as shown below:



• A variety of in situ thermal treatment technologies have been either demonstrated or developed through DOE, DOD, and EPA programs. The aggregate experience with these programs enhances confidence in the fundamentals of DUS. Full-scale demonstrations of these related technologies include those shown in the table on page 9.

Competing Technologies (continued)

Technology	Developer	Basic Principle	Status/Comments
DOE			
1 Six-Phase Soil Heating	Pacific Northwest Laboratory (PNL)	Combines electrical heating with soil vapor extraction (six-phase distributes energy better)	Full-scale demonstration at DOE Savannah River as part of the VOC in Non-Arid Soils and Ground Water Integrated Demonstration in 1993; partnering/licensing discussions ongoing
2 Thermal Enhanced Vapor Extraction	Sandia National Laboratories (SNL)	Combines soil vapor extraction with powerline frequency (ohmic/electrical) and radio-frequency soil heating	Full-scale demonstration planned in 1994 at SNL chemical waste landfill in part of the Mixed Waste Landfill Integrated Demonstration; builds upon previous demonstrations at Volk Field, WI, Rocky Mountain Arsenal, CO, and Kelly AFB, TX (see EPA projects)
3 Radio Frequency Heating	KAI Technologies, Inc.	Radio frequency heating of soils combined with soil vapor extraction	Field demonstrated on VOC contaminated soils using a horizontal well at the DOE Savannah River Site as part of the VOC in Non-Arid Soils and Ground Water Integrated Demonstrationin 1993
EPA/DOD			
1 Contained Recovery of Oily Wastes (CROW ™)	Western Research Institute	Steam or hot water displacement guides contamination to extraction wells	EPA SITE field demonstration underway at the Pennsylvania Power & Light Brodhead Creek Superfund site, PA; pilot-scale demonstrations completed at a wood treatment site in Minnesota
2 HRUBOUT® Process	Hrubetz Environmental Services, Inc.	Hot air injection combined with a surface exhaust collection system	EPA SITE field demonstration on JP-4 contaminated soils completed at Kelly AFB, TX, in 1993
3 In Situ Steam and Air Stripping	Novaterra, Inc. (formerly Toxic Treatments USA, Inc.)	Portable steam and air injection device (Detoxifier ™) used in soils	EPA SITE field demonstration conducted on VOC and SVOC contaminated soils at the Annex Terminal, San Pedro, CA, in 1989
4 In Situ Steam Enhanced Extraction Process	Praxis Environmental Technologies, Inc.	Steam injection/vacuum extraction (same as 5 and 7)	Field demonstrations underway at Hill AFB, UT, and McClellan AFB, CA
5 In Situ Steam Enhanced Extraction Process	Udell Technologies, Inc.	Steam injection/vacuum extraction (same as 4 and 7)	Field demonstrations underway at Naval Air Stations Lemoore and Alameda in California; Udell technologies no longer in existence
6 Radio Frequency Heating	Illinois Institute of Technology Research Institute/Halliburton NUS	Radio frequency heating of soils combined with soil vapor extraction	EPA SITE field demonstration completed at Kelly AFB, TX, in 1993; earlier demonstrations occurred at Rocky Mountain Arsenal, CO, and Volk Field, WI; demonstration cofunded by DOE
7 Steam Enhanced Recovery System	Hughes Environmental Systems, Inc.	Steam injection/vacuum extraction (same as 4 and 5)	EPA SITE field demonstration completed at the Rainbow Disposal Site in Huntington Beach, CA, from 1991 to 1993; Hughes no longer offering technology

Further information on these full-scale applications is available in references 16 (DOE programs) and 5 (DOD/EPA programs). In addition EPA's Vendor Information System for Innovative Treatment Technologies (VISITT) electronic database lists additional suppliers of equipment and services related to in situ thermally enhanced recovery of contaminants. These include:

- Bio-Electrics, Inc., Kansas City, MO
- EM&C Engineering Associates, Costa Mesa, CA
- SIVE Services, Dixon, CA
- Thermatrix, Inc., San Jose, CA

SECTION 5
COST

Cost Estimate for Future Applications

LLNL researchers have developed projected costs for applying DUS to other sites based upon demonstration results (actual costs for demonstration at LLNL are presented in Appendix E). An estimate was prepared for remediating a shallow (less than 50 ft in depth) chlorinated solvent spill. The proposed implementation approach involved successive application of DUS to 10,000 yd^3 cells by relocating equipment to various locations at the site. Key results of the cost estimate were as follows:

- Cleanup of the entire site (an estimated volume of 20,000 to 40,000 yd^3) would cost approximately \$28/yd^3.
- A pilot treatability study using full-scale equipment would cost \$37/yd^3. Economics improve as the area to be remediated increases; LLNL researchers believe that larger sites could be engineered to cost \$11-15/yd^3.
- The total cost for DUS implementation was estimated to be less than the first-year cost of constructing and operating a conventional groundwater pump-and-treat facility.

The following table details the equipment and labor costs associated with the treatability demonstration, full-scale operation for the first two 10,000 yd^3 treatment cells, and subsequent pairs of 10,000 yd^3 treatment cells.

	Treatability Demonstration			*Full-Scale Remediation*	
Equipment Costs	*Per Site Non-Reusable*	*Per Site Monthy Rental*	*Per Site Reusable*	*Incremental Cost for Next Two Treatment Cells*	*Average Cost for Additional Pairs of Treatment Cells*
Steam Equipment					
Boiler rental		$15,000		$15,000	$15,000
Boiler manifold			$2,000		
Steamhose (200 ft)			$2500		
2 ea wellhead fittings			$4,000		
6-in black pipe (wells)	$600			$300	$150
Compressor for pumps and boiler control		?	$15,000		
2 ea 6-in x 20 ft stainless steel (ss) well screens	$2,400		?	$1,200	$600
Surface coolings/confinement barriers.		$5,000			
Extraction Well Equipment					
8 ea downhole pumps		$50,000			
8 ea 6 in x 20 ft SS screens	$9,500		?	$3,200	$3,200
6-in black pipe	$1,200			$400	$400
Wellhead fittings and Instrumentation			$16,000		
ERT/Monitoring Equipment					
2-in fiberglass pipe (40 ft/well)	$6,300			$400	$400
2-in fittings for fiberglass pipe	$4,000			$267	$267
Electrical wire and electrodes	$3,990			$266	$266
Computer equipment			$15,000		
Thermocouple wire	$4,000				
Thermocouple monitoring system			$4,000		
Surface Treatment Equipment					
Air stripper (water treatment)			?		
Vacuum pump for extraction wells			$15,000		
Fiberglass extraction piping			$3,000		
4-in fiberglass pipe fittings			$5,000		
Cyclone cylinder			?		
Condenser			?		
Cooling tower			?		
Product/water separater			?		
25,000 gal treated water storage tanks		$3,000			
Storage tanks for separated product		$1,000			
Incidental Surface Equipment					
Forklift rental ($2000/month)		$2,000		$2,000	$200
Crane rental ($100/day)		$500		$500	$500
Barricades, fencing, etc.		$1,000		$1,000	$800
Miscellaneous small equipment		$5,000		$1,000	$500

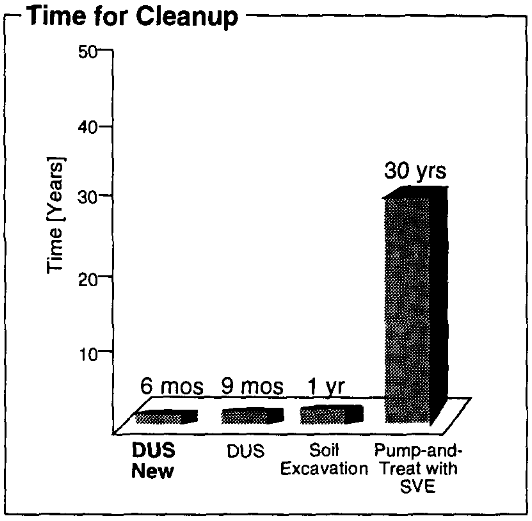
Cost Estimate for Future Applications (continued)

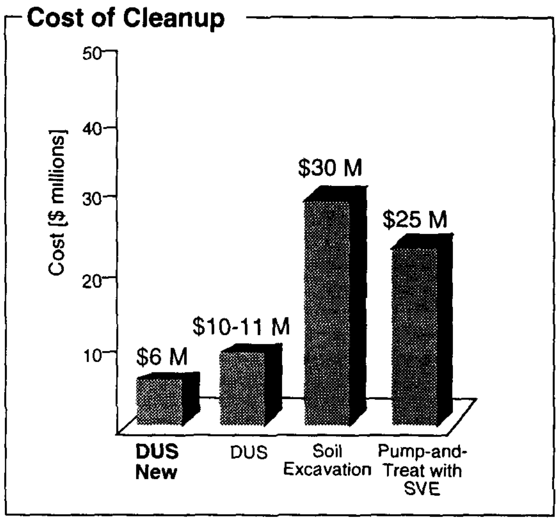
	Treatability Demonstraton	Full-Scale Remediation	
Equipment Costs (continued)	*Total Costs*	*Incremental Cost for Next Two Treatment Cells*	*Average Cost for Additional Pairs of Treatment Cells*
Replacement costs for consumable equipment		$8,580	$17,160
Non-reusable equipment total (demonstation only)	$31,790		
Reusable equipment total (demonstration only)	$171,600		
Shipping (10% of equipment costs)	$20,089		
Total rental costs for 6 months onsite	$135,000		
Equipment contingency (15% of equipment costs)	$33,884		
Procurement cost-LLNL (estimated at 19.78%)	$77,609	$7,782	$6,945
Total equipment costs	***$469,972***	***$42,895***	***$46,268***
Labor Costs			
Engineering/Scientific Labor from LLNL/UC/Commercial Partners			
Planning/design/consultation (4 FTEs for 3 months)	$230,000	$23,000	$23,000
Characterization/Installation (6 FTEs for 2 months)	$230,000	$23,000	$23,000
Operation (2 FTEs for 6 mosnths)	$230,000	$23,000	$23,000
Evaluation/reporting (4 FTEs for 1 month)	$75,000	$7,500	
LLNL/UC Technical Labor			
ERT electrode preparation	$10,000	$2,000	
Pressure testing wellheads	$10,000	$2,000	
ERT installation (1 FTE for 1 month)	$10,000	$2,000	
Monitoring system operation	$40,000		
Commercial Partner Technical Labor			
Wellhead pump installation (4 FTEs for 1 month)	$40,000	$20,000	$15,000
Regulatory compliance monitoring (1/2 FTE, 6 months)	$57,500		
Health and safety monitoring (1FTE for 6 months)	$118,000		
Operation (1 FTE for 6 months)	$116,000	$57,500	$43,125
Boiler operator (1 FTE, 24 hr/day, 5 months @ $75/h)	$270,000		
Treated water disposal costs (based on LLNL rates)	?		
Analytical process chemistry	$50,000	$25,000	$12,500
Installation Expenses			
10 ea extraction/injection wells	$20,000	$10,000	$4,000
10 ea monitoring/ERT wells with chemist	$45,000	$15,000	$11,250
Treatment system hookup/lasting (4 FTEs for 1 month)	$40,000	$20,000	$20,000
Miscellaneous/Travel/Overhead			
Travel (40 person trips @ $1500/trip)	$60,000	$10,000	
Miscellaneous supplies and expenses	$20,000	$4,000	
Overhead/etc. nonwage nonprocurement at 64.89%	$51,912	$9,085	
Labor subtotal	$2,189,384	$295,978	$221,163
Labor contingency (25%)	$547,346	$73,995	$55,291
Total labor costs	***$2,737,000***	***$390,000***	***$278,000***

NOTE: All costs are preliminary approximations for work within the DOE environment (overhead, travel, and procurement charges may be less for other applications). Costs not specified in this estimate include costs for disposal of boiler blowdown (if any) and equipment for offgas treatment (see Appendix E for vapor phase equipment costs during demonstration).

Cost Savings Versus Alternative Technologies

LLNL researchers compared DUS costs and remediation times with estimated costs and cleanup times of applying alternative technologies at the GSA:





Notes: DUS New = cost of commercial application of DUS at the GSA; assumes 40% reduction from demonstration costs due to use of lessons learned and elimination of research-oriented activities; detailed in Appendix E
DUS = cost of demonstration program for DUS
Soil Excavation includes relocation of underground utilities
SVE = soil vapor extraction

SECTION 6

REGULATORY/POLICY REQUIREMENTS & ISSUES

Regulatory Considerations

Permit requirements for future applications of DUS are expected to include:

- air permits for operation of steam generation equipment and discharge from surface treatment equipment (i.e., air stripper, GAC units, or internal combustion engine)
- liquid effluent discharge permits from aboveground treatment systems (discharge criteria are likely to be related to ground water cleanup levels)

For applications in some states, underground injection permits may be required for system application.

Permitting requirements and regulatory considerations arising from the demonstration at LLNL and relevant to future applications elsewhere are detailed below.

Water

- Ground water cleanup levels have been established for the major contaminants at the GSA:

COMPOUND	*FEDERAL MCL (ppb)*	*CALIFORNIA MCL (ppb)*	*NPDES LIMIT (ppb)*
Benzene	5	1	0.7
Toluene	1,000	-	5
Ethyl benzene	700	680	5
Xylenes (total)	10,000	1,750	5
Total VOCs	-	-	5

NOTE: MCL = Maximum Contaminant Level; NPDES = National Pollutant Discharge Elimination System

- Remediation will continue until in situ soil concentrations are deemed not to adversely impact groundwater. Those levels are determined through monitoring and modeling efforts as well by using the criteria listed above.

6

Air

- The timetable for the DUS demonstration was dictated by the air permits issued for the project. The system was shut down while it was still removing 50 gal/day of gasoline, and an unheated region remained because the air discharge allowances had been consumed.

- The boiler for steam generation utilized Best Available Control Technology (BACT) consisting of a low NOx burner design and flue gas recirculation to control NOx emission to 40 ppm. The Bay Area Air Quality Management District (BAAQMD) granted a research exemption for the project instead of requiring LLNL to purchase an emission allotment of 2,200 lbs (1.6 lbs/hr) of NOx.

- The BAAQMD issued permits for the following:

DISCHARGE	*COMPOUND*	*SAMPLING FREQUENCY*	*DISCHARGE LIMIT*
Air stripper	Total hydrocarbons	5/wk	10 ppm
GAC	Total hydrocarbons	5/wk	10 ppm
IC engine	Total hydrocarbons	5/wk	Destruction > 98.5%
Sitewide benzene	Benzene	Monthly	1.815 lbs/day

- The LLNL DUS demonstration project incurred one violation from the BAAQMD because of higher than anticipated concentrations of VOCs in extracted vapor streams exceeding the capacity of surface treatment systems.

Regulatory Considerations (continued)

Other Considerations

• Waste forms generated by DUS include the air and liquid discharges (effluent limitations listed above) as well as spent activated carbon. The carbon can be either regenerated or landfilled and poses no unusual regulatory or permitting burden.

• As dictated in the LLNL sitewide Record of Decision and Remedial Implementation Plan, project milestones for site cleanup specify dates for designing and starting various treatment facilities to satisfy overall objectives of protecting human health and the environment in the shortest time possible. DUS represents the most rapid alternative identified during feasibility studies for achieving these objectives.

• No anticipated regulatory developments are expected to change the ability of DUS to comply with relevant requirements. Use of the technology at sites other than LLNL is not expected to be conducted under more stringent requirements. In some cases, permitting of airborne discharges may be easier.

Safety, Risks, Benefits, and Community Reaction

Worker Safety

• Operational Safety Procedures were developed to address DUS-specific safety issues not covered by existing LLNL procedures. Areas of concern included hazards posed by the steam generating equipment, electrical hazards from the large currents utilized, proper handling of pressurized steam injection wells, and hazards posed by implementation of ERT.

• Although large amounts of contaminants are more quickly extracted from the ground with DUS than with conventional technologies, safety measures for handling extracted liquid and vapor streams are similar to those for the conventional technologies. One exception, however, is that in some instances the contaminant concentrations of extracted vapors exceeded the upper explosive limits for the mixture.

• Level D personnel protection was used during installation and operation of DUS.

Community Safety

• Although DUS involves handling extracted vapor and liquid streams with higher concentrations of contaminants than conventional technologies, the dramatically increased speed of cleanup reduces long-term risks to nearby populations.

• DUS employs real-time monitoring controls, which greatly reduces the likelihood of accidents or offsite migration of contaminants.

Environmental Impacts

• DUS speeds cleanup relative to conventional technologies freeing land for beneficial reuse. Contaminants are either destroyed or are concentrated, transferred to other media, and disposed of offsite depending upon the configuration of surface treatment equipment.

Socioeconomic Impacts and Community Perception

• Unlike some other long-term remedial alternatives, DUS will require a staff only for a limited period of time. Selection of DUS can reduce the amount of time an environmental restoration work force is needed at some installations.

• DUS has received positive support from the general public at the LLNL Community Work Group Meetings. The basic principles of the technology have been readily understood by both technical and nontechnical audiences.

SECTION 7
LESSONS LEARNED

Design Issues

• The DUS demonstration made use of an existing groundwater treatment facility designed to treat gasoline and low levels of chlorinated solvents for the design life of 30 years. The facility utilized oil/water separation, UV/H_2O_2, and GAC for the liquid phase and GAC for the vapor phase. This design was not optimal for DUS conditions. The large vapor flows loaded with fuel hydrocarbons required installation of an internal combustion engine to replace the GAC. The high temperature process created conditions unfavorable to UV treatment (increased carbonates and silicates in the extracted liquids would come out of solution when cooled in the UV unit). Packed tower air stripping may be more appropriate for similar applications in the future.

• The success of the DUS process is dependent upon boiling the subsurface environment. The process must be designed not only to bring soil and groundwater to steam temperature but to impart a large amount of energy to create a complete steam zone. Sufficient steam must be injected to counter the cooling effects of inflow of ground water into the treatment zone.

• Aboveground treatment systems must be sized to handle anticipated peak extraction rates and the expected distribution of VOCs in extracted vapor and liquid streams. During demonstration, the majority of extracted VOCs were in the vapor stream. Initially, the vapor treatment system was undersized to handle this stream.

• Aboveground treatment systems must be located so as not to interfere with access to the subsurface treatment zone. This is necessary to avoid situations in which additional injection, extraction, heating, or monitoring wells need to be installed in a spot occupied by surface equipment.

Implementation Considerations

• Effective removal of contaminants from the subsurface requires repeated creation of the steam zone by successive phases of steam injection and continuous vacuum extraction. The pressure changes created by this oscillatory approach distill contaminants from pore spaces in both saturated and unsaturated sediments.

• Operational difficulties encountered included biofouling from microorganisms destroyed by steaming, scaling and deposits on sensors, and clogging from fines brought to the surface. Maintenance plans must address these situations in future applications by scheduling for routine cleaning of equipment.

• Extraction rates can vary greatly depending upon the amount of steam injected, the total vacuum applied, and cycle times.

• Permitting of air discharges from both aboveground treatment units and equipment used to supply steam energy is an issue requiring early attention.

• DUS is a labor intensive process requiring significant field expertise to implement.

• ERT proved to be the most effective method for monitoring the DUS process in real time. Alternative geophysical techniques could be used for other applications.

Technology Limitations/Needs for Future Development

• Data on long-term routine operating experience with DUS are not yet available but are needed to better plan future applications.

• Treated soils can remain at elevated temperatures for months and even years after cleanup. This could impact site reuse plans. Soil venting can greatly accelerate the cooling process.

• Future development needs currently identified for DUS include demonstrating the process for removing chlorinated solvents including DNAPLs, mixed wastes, and sites with fractured subsurface media, automating monitoring techniques, and further refining system design and operating techniques.

Technology Limitations/Needs for Future Development (continued)

• DUS is effective in th‹ presence of free-phase and dissolved-phase contaminant liquids. It is extremely effective in the absence of liquio‿ (vadose zone), but is usually not cost effective versus alternative technologies in these instances.

• DUS is not applicable at depths less than five feet. At greater depths, the steam injection pressure can be increased which produces higher efficiences and extracts more work from each well. (More information on technology applicability is located in Section 4 and Appendix D.)

Technology Selection Considerations

• DUS was effective at quickly removing concentrated free-product contaminants, including materials sorbed to saturated sediments, without mobilizing contaminants outside the treatment zone.

• Steam injection is effective at heating permeable zones, and repeated steam passes, when combined with electric heating, can heat adjacent impermeable areas.

• Electrical heating is effective on clay zones; however, power requirements increase when extracting hot fluids from the treatment zone.

• Future applications of DUS will be designed to focus on mobile/temporary aboveground treatment and steam injection systems that can treat plumes on a cell by cell basis.

• DUS is compatible with long-term efforts to bioremediate residual contamination following steam injection. After application of DUS at LLNL, viable microbial populations continued to degrade gasoline at the site at temperatures above 158°F. Although microbial populations present after application of DUS were different from those present before treatment; the treatment zone was not sterilized.

• DUS can compare favorably in terms of speed, effectiveness and cost with alternative technologies for deep subsurface plumes. At LLNL, significant cost savings were realized from DUS as opposed to installation of soil vapor extraction/pump-and-treat systems or excavation of contaminated areas. Further reductions in DUS cost are anticipated as experience is gained that will optimize subsequent applications.

APPENDIX A

DEMONSTRATION SITE CHARACTERISTICS

A

Site History/Background

- The 800-acre LLNL site was converted from agricultural use into a flight training base and aircraft assembly and repair facility by the Navy in 1942. In 1951, the Atomic Energy Commission converted the site into a weapons design and basic physics research laboratory. Later site missions have included programs in biomedicine, energy, lasers, magnetic fusion energy, and environmental science.

- Initial releases of hazardous materials occurred in the mid to late 1940s. There is also evidence that subsequent localized spills, leaking tanks and impoundments, process cooling water, and landfills released VOCs, FHCs, lead, chromium, and tritium to sediments and groundwater primarily from 14 major source areas of contamination.

- Between 1952 and 1979, based upon inventory records, as much as 17,000 gallons of leaded gasoline was released from underground storage tanks (USTs) beneath a gasoline filling station in an area now designated the GSA. The GSA occupies an approximately 1.25-acre level area at the southern edge of LLNL and is the site of the DUS application.

- Land north and south of the site is zoned for industrial use, high-density urban areas are west of the site, and the east side is primarily agricultural. Immediately south of the GSA are facilities owned and operated by Sandia National Laboratories. The climate is semiarid with annual precipitation of around 14 inches/year.

- Corrective actions taken since 1988 at the GSA have included the removal and sand filling of four USTs, installation of a gas skimmer which removed 100-150 gal of gasoline, soil vapor extraction of about 1900 gal, and intermittent use of a groundwater pump-and-treat system using UV/H_2O_2 treatment. A large subsurface microbiological population indicates that indigenous microbes have metabolized additional gasoline constituents.

Contaminants of Concern

Contaminants of concern focused on during the remediation are:

- benzene,
- toluene,
- ethylbenzene,
- xylene (mixture of m, o, and p-xylenes), and
- 1,2-dichloroethane.

Low levels of other chlorinated solvents are also present in the GSA but were not specifically targeted by DUS remediation efforts.

Property at STP*	Units	B	T	E	X
Empirical Formula	-	C_6H_6	$C_6H_5C_2H_5$	$C_6H_5CH_3$	$C_6H_4(CH_3)_{2m}$
Density	g/cm^3	0.87	0.87	0.87	~0.87
Vapor Pressure	mmHg	75	29	7	10
Water Solubility	mg/L	1,780	534	161	178
Octanol-Water Partition Coefficient; K_{ow}	-	132	490	1,413	1,830
Organic Carbon Partition Coefficient; K_{oc}	-	50	339	565	255

STP = Standard Temperature and Pressure; 1 atm, 25 °C

Nature and Extent of Contamination

- The volume of FHC as gasoline before any remediation efforts was estimated based on soil and ground water sampling to be approximately 16,000-17,000 gal: 6,000 in the vadose zone, 10,000-11,000 in saturated sediments, and 100 dissolved in ground water. Mass volume estimates made immediately before application of DUS identified approximately 6,500 gal of gasoline within the treatment zone.

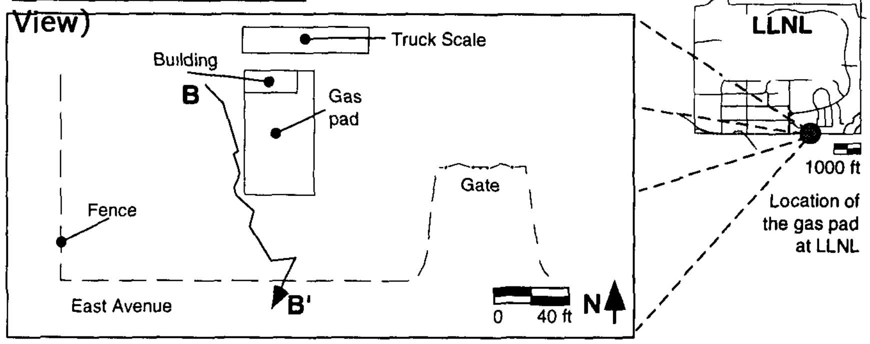
- High concentrations of gasoline in saturated sediments indicated the likelihood of free phase gasoline. The free phase was trapped within low-permeability sediments below a ground water table that has risen 10 to 30 ft since the time of the main portion of the release (1979) because of the cessation of agricultural pumping.

- FHC concentrations exceed 10 ppm only in the immediate vicinity of the release point with concentrations decreasing to 1 ppm and 100 ppb at 35-40 ft and 40-45 ft, respectively. Benzene levels above 1 ppb [California MCL is now 0.5 ppb] are found within 300 ft. FHCs were not found below a depth of 150 ft.

Contaminant Locations and Hydrogeologic Profiles

The GSA has been extensively studied since 1984. Over 70 subsurface borings and monitoring wells revealing the area's geologic, physical, and chemical characteristics have been completed. Short- and long-term drawdown, injection, and extraction tests were conducted to assess hydraulic properties. Pneumatic data derived from soil vapor extraction efforts have also been collected.

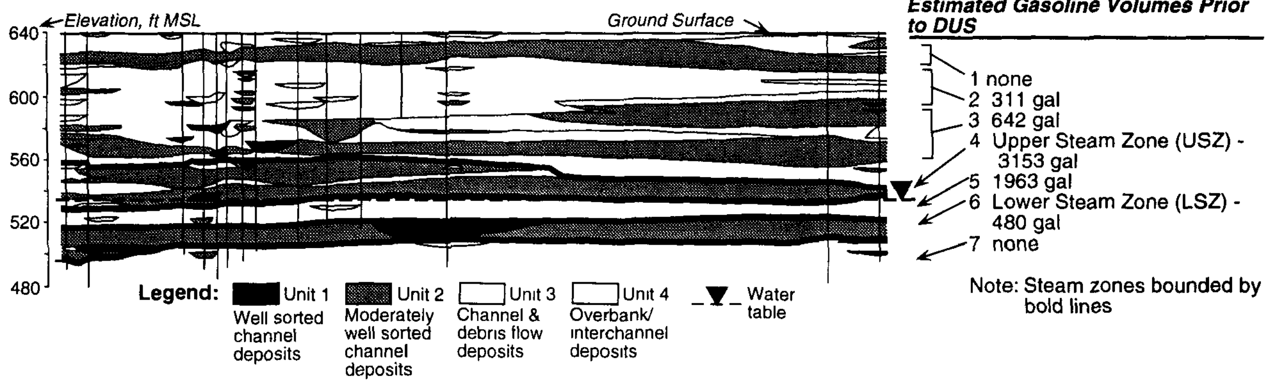
Site Layout (Plan View)



Cross-Sectional View

Four hydrogeologic units and seven hydrostratigraphic layers have been identified along cross-section B-B' shown in the plan view above. An FHC concentration profile along this cross-section is provided in Section 3.

Hydrostratigraphic Layers with Estimated Gasoline Volumes Prior to DUS



Hydrogeologic Unit Characterization

#	Hydraulic Conductivity Range [gpd/ft2]	Interpreted Permeability
1	15 to 1070	Very high to high (mean=280)
2	13 to 1000	High to moderate (mean=154)
3	16 to 170	Moderate to low (mean=116)
4	<5 to 18	Low (mean=11)

Hydrostratigraphic Layer Characterization

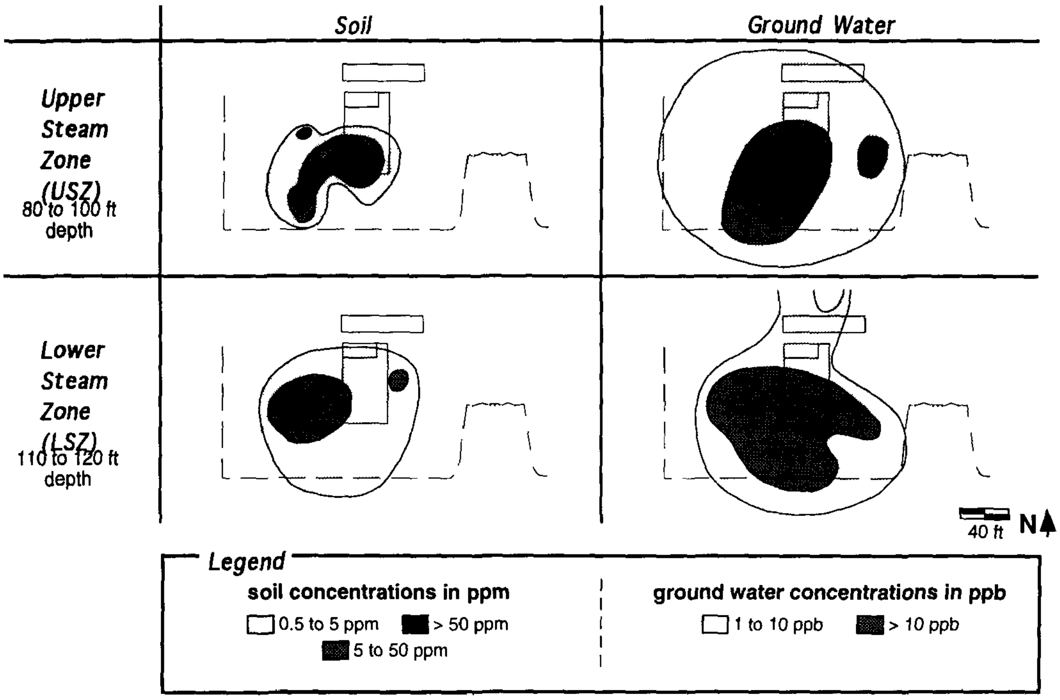
1 5-15-ft-thick interval of coarse-grained high-permeability sandy gravels and gravelly sands
2 30-ft-thick, laterally continuous interval of clayey silts to silty clays
3 very heterogeneous zone of elongated lenses of channel sands and gravels interbedded with intervals of silty clays and clayey silts from 50 to 80 ft depth; forms aquitard over USZ
4 partially saturated water-bearing zone composed of a heterogenous mix of high to low permeability sandy to clayey gravels and gravelly to silty sands, 80 to 100 ft depth
5 low-permeability silty clays and clayey silts; forms barrier between the USZ and LSZ
6 high-permeability laterally continuous gravelly sands and sandy gravels; average thickness of 11 ft
7 laterally continuous sequence of silty clays to clayey silts at least 15 ft below base of LSZ

NOTE: The two steam zones appear to be hydraulically isolated from adjacent aquifers, are relatively permeable, and contain the most elevated FHC concentrations.

- The site is underlain by several hundred feet of complexly interbedded alluvial and lacustrine sediments.
- Depth to ground water in the GSA is approximately 100 to 120 ft.
- Regional ground water flow is generally westward, locally stratified, and primarily horizontal.
- Pumping tests and the distribution of contaminants at LLNL indicate a high degree of horizontal subsurface communication. Minimal observed communication in the vertical direction and the layered alluvium restricts downward migration of contaminants.

Contaminant Locations and Hydrogeologic Profiles (continued)

Areal Extent of Benzene Contamination (before application of DUS)

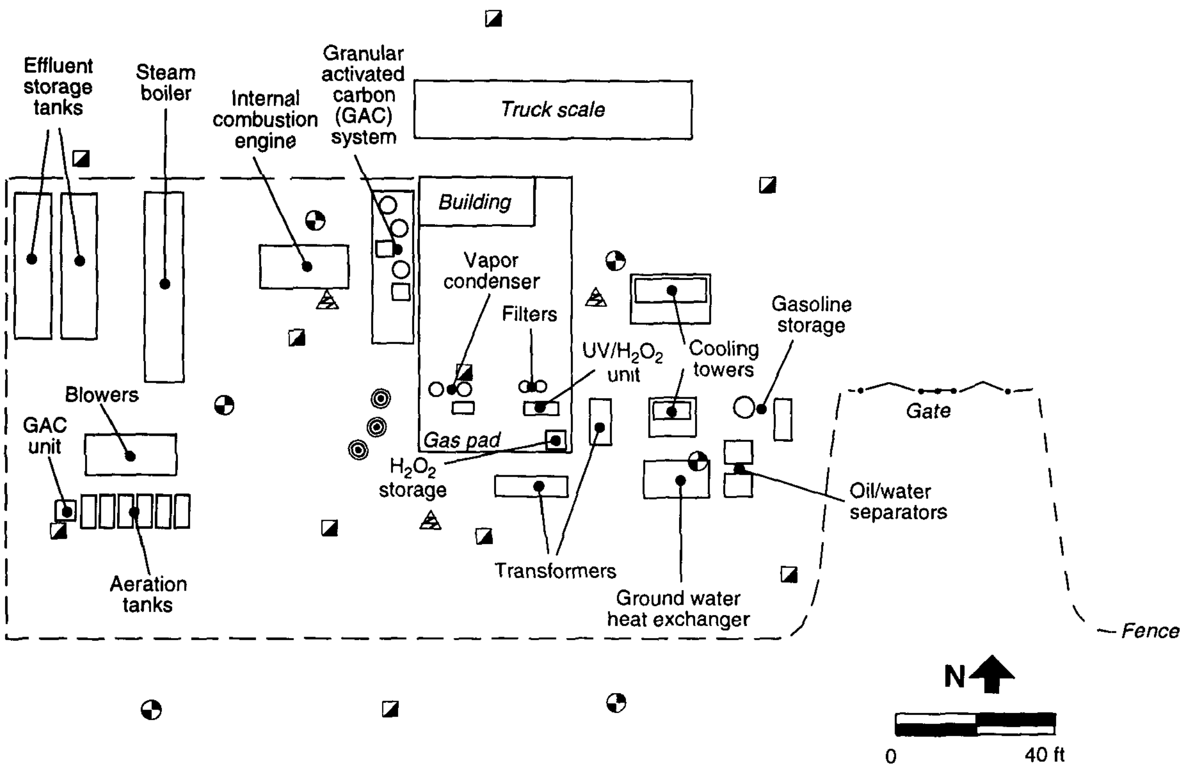


APPENDIX B

TECHNOLOGY DESCRIPTION DETAIL

B

System Configuration



NOTE: 21 tiltmeters (not shown) were also utilized. Additional subsurface borings and ground water monitoring wells are present from initial and ongoing characterization activities

Operational Requirements

- Typical staffing requirements for future applications of DUS, at sites of size similar to that of LLNL, are anticipated to include:

  one project engineer,
  one or two geophysicists to handle ERT and temperature monitoring and data interpretation,
  four certified boiler operators (one operator needed 24 hours/day),
  four effluent treatment technicians/sampling technicians (one technician needed 24 hours/day),
  one chemical data analyst, and
  one electrician available for periodic maintenance.

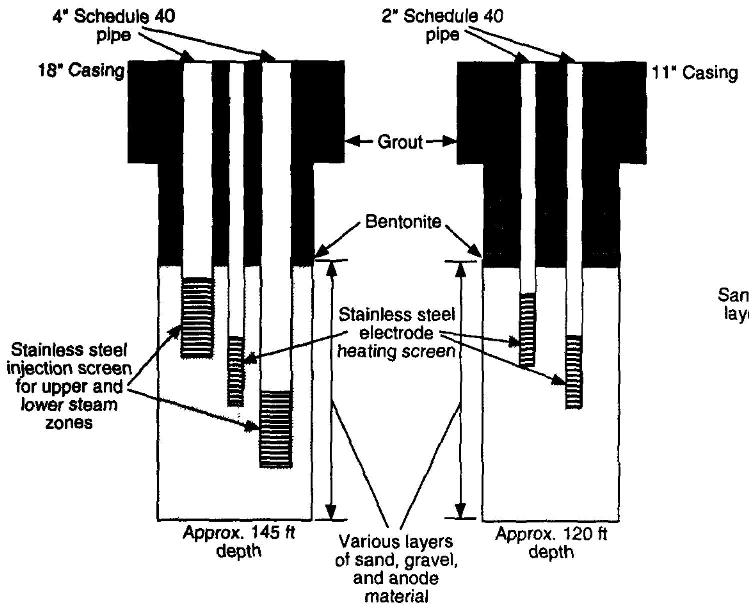
- DUS consumes significant quantities of electricity, water, and, for some applications, natural gas. These requirements can be handled via hookups to existing facilities or can be stored or generated onsite for more remote applications.

B

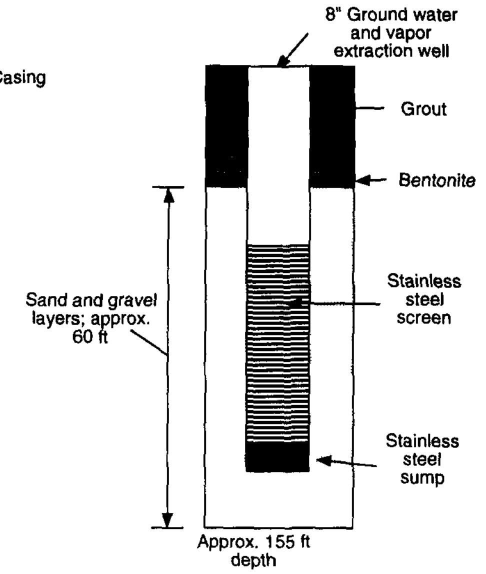
Well Close-Ups

Thermal Enhancement

Steam Injection/ Electrical Heating ***Electrical Heating***

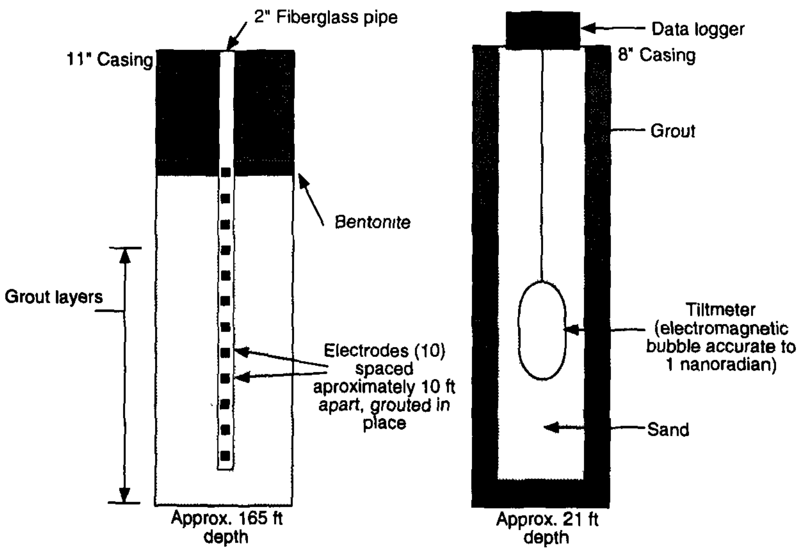


Extraction



Monitoring

Geophysical Monitoring ***Tiltmeter***

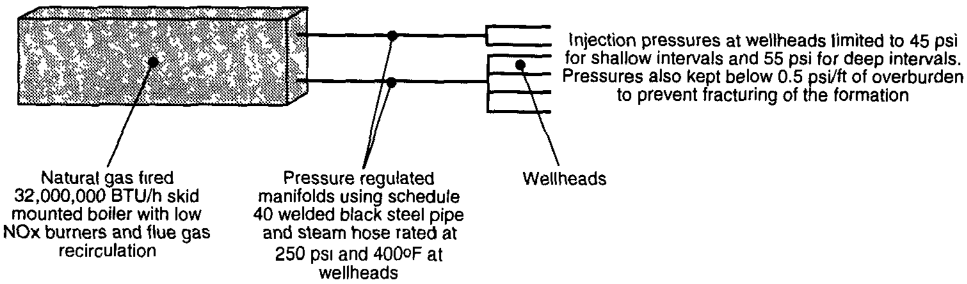


Thermocouples (not shown) are present in the monitoring, steam injection, and electric heating wells

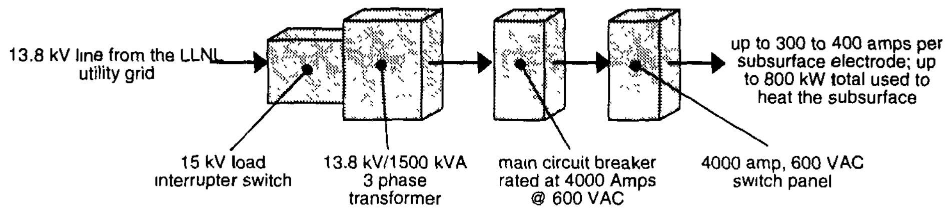
All drawings not to scale

Surface System Schematics

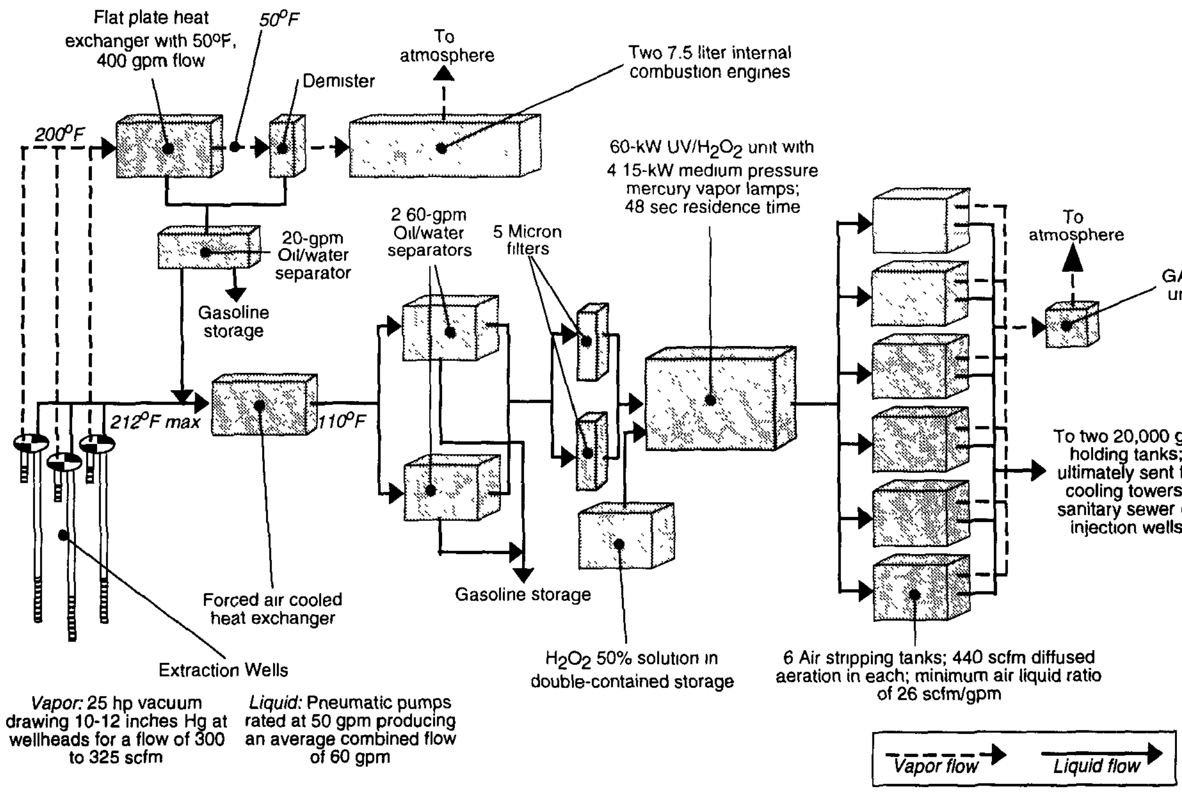
Steam Injection Surface Equipment



Electrical Heating Surface Equipment

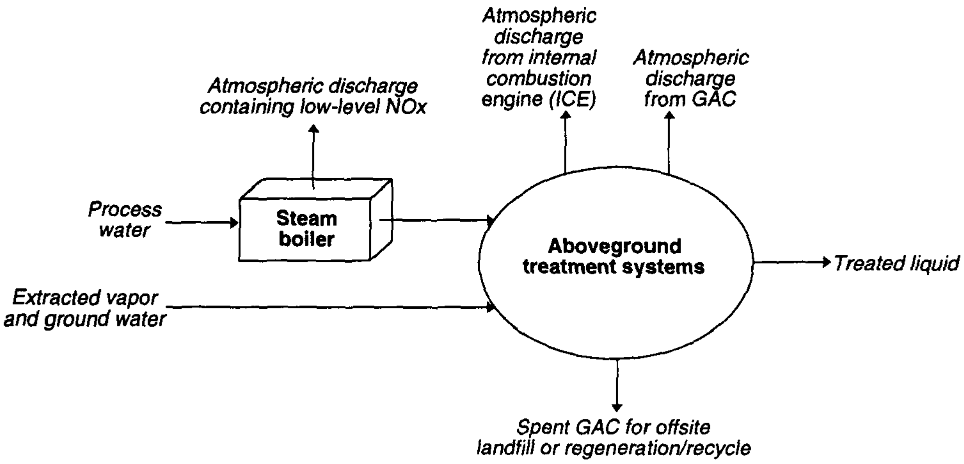


Extracted Liquid and Vapor Treatment Equipment



- The configuration shown above was used for the second DUS steam pass. The most significant difference from the first pass was the installation of the internal combustion engines to replace a regenerable carbon adsorption unit **that** could not handle the higher than anticipated vapor flow rates and hydrocarbon concentrations.

Waste Generation/Process Influents and Effluents



APPENDIX C
PERFORMANCE DETAIL

Operational Performance

Maintainability and Reliability

- A significant percentage of the field activities occurred in a shakedown mode where various processes were debugged and optimized. In addition, distinct demonstration phases used different equipment configurations; therefore, long-term routine maintenance and reliability data are not available.
- Operational difficulties encountered included biofouling (especially from microorganisms destroyed by steaming), scaling and deposits on sensors, clogging from fines brought to the surface, and difficulties in maintaining the cycling, pressure varying, high-temperature process.

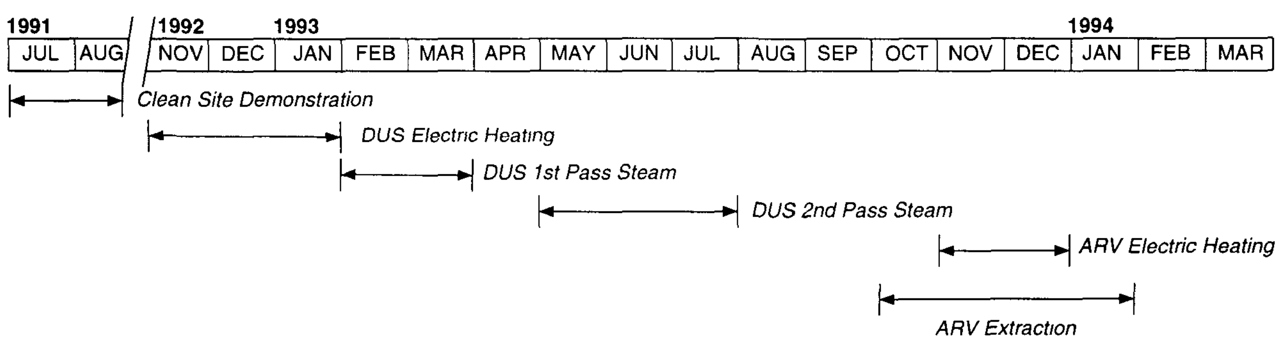
Operational Simplicity

- DUS requires real-time in-the-field expertise to interpret monitoring data and appropriately adjust injection and extraction flow rates. Staffing requirements are presented on page B1.
- Routine implementation practices have not yet been developed for all aspects of DUS. Future development efforts will include consideration of automating certain process monitoring activities.

C

Schedule

Major Phases of the Demonstration Program



Performance Validation

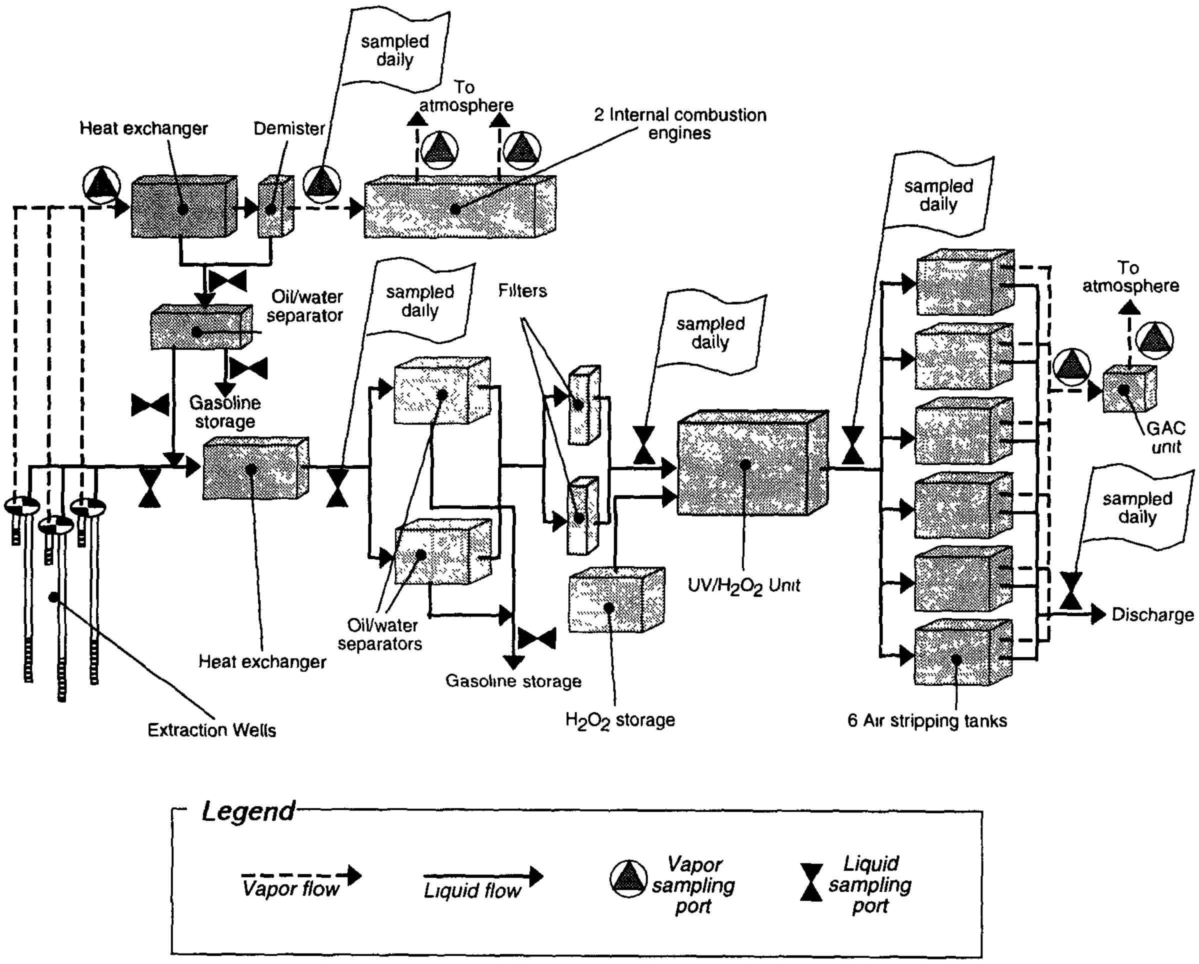
- The EPA Superfund Innovative Technology Evaluation (SITE) program installed two soil borings for analysis of post-treatment conditions during the DUS demonstration. The results corroborated the data on pre- and post-treatment soil conditions developed by LLNL researchers.
- Although DUS has not been applied at any other sites, the principle of in situ thermal treatment has been demonstrated and validated through other DOE, DOD and EPA sponsored projects which are discussed in Section 4.

Sampling, Analytical, and QA/QC Issues

Sampling and Analysis Objectives

- Obtain concentrations for calculating daily contaminant removal from vapor and liquid streams.
- Characterize the contamination removed.
- Measure destruction efficiencies of the surface treatment systems for regulatory compliance.
- Compare results with on-line monitoring instrumentation.

Sampling Locations/Procedures



- Aqueous samples were collected in 40-ml volatile organic analysis (VOA) vials after three line volumes passed through each port unsampled.
- Free product samples were collected from the megators and placed into 40-ml VOA vials.
- All liquid phase samples were cooled to 4°C until analysis.
- Evacuated 500-ml stainless steel spheres of Tedlar bags were plumbed in-line with sampling ports for collection of vapor samples.

Sampling, Analytical, and QA/QC Issues (continued)

Analytical Methods

- Aqueous samples were analyzed onsite according to EPA methods 601/602 and 8015 [total petroleum hydrocarbons (TPH)].
- Sudan IV was used as a petroleum indicator to visually determine the presence of gasoline in aqueous samples. These experiments were conducted on surplus sample volumes subsequent to gas chromatography (GC) analysis
- GC/mass spectroscopy (GC/MS) analyses of recovered free product were performed offsite to determine composition changes with time.
- Vapor samples were analyzed onsite in accordance with EPA method T014.
- Results of onsite analyses were available within 24 hours of sampling to implement necessary changes in extraction rates and treatment facility operations.

Equipment

- TPH analyses were performed using an autosampler and purge-and-trap concentrator coupled to a Hewlett Packard (HP) 5890 Series II GC equipped with a flame ionization detector.
- EPA 601/602 and T014 analyses were performed using an HP 5890 Series II GC outfitted with an autosampler, photoionization detector, electrolytic conductivity detector, purge and tap concentrator, and low dead volume injector port.
- An HP Chemstation, an automated GC systems control and data acquisition workstation was used to gather, process, and archive GC data.

QA/QC Issues

Liquid Phase

- Quality control limits were set for surrogate recoveries, field spike recoveries, and precision and accuracy.
- The Internal Standard method was used for data calculation and reporting.
- Limits of detection were set using American Chemical Society recommendations.
- Three-point calculation checks were run daily.
- Instrument calibration was performed at least quarterly or as needed (determined by daily checks).
- Method blanks were run every 3 to 4 unknown samples.

Vapor Phase

- Quality control limits were set for precision and limits of detection. Vapor samples were not spiked; therefore, accuracy was not calculated.
- Stainless steel spheres were cleaned, pressure-checked, and analyzed for EPA 601/602 compounds before use.
- Two-point calibration checks were run daily.
- Instrument calibration was performed quarterly or as needed (determined by daily checks).

C

Intellectual Property Rights (continued)

Existing/Pending Patents

- Twelve patent applications have been filed for different processes and designs.
- To date, two patents have been issued:
    - Patent 5,018,576 "Process for In Situ Decontamination of Subsurface Soil and Groundwater," K.S. Udell, N. Sitar, J.R. Hunt, and L.D. Stewart assignors to The Regents of the University of California and
    - Patent 5,325,918, "Optimal Joule Heating of the Subsurface," J. Berryman and W.D Daily, assignors to the United States of America as represented by the DOE.

Licensing Information

- DUS technology is commercially available through UC Berkeley/LLNL, who are currently negotiating nonexclusive licenses with several government and private parties (see Contacts section below for further information).
- LLNL has received hundreds of inquiries from site owners concerning the potential applicability of DUS to their sites. This level of interest combined with the attention focused upon other in situ thermal treatment technologies attests to the broad market for DUS. Specific commercialization activities already initiated by LLNL include:
    - performing a feasibility and cost analysis to remediate a chlorinated solvent-contaminated site at the DOE Pinellas facility,
    - the design of a system to remediate shallow underground hydrocarbons at a U.S. Navy facility in California,
    - the conceptual design to remediate a large shallow fuel-contaminated U.S. Army Corps of Engineer managed site in Alaska, and
    - other private sector projects.

These efforts are part of LLNL efforts to transfer DUS know-how to new licensees of the technology.

D

APPENDIX E

COST DETAIL

Demonstration Costs

• DUS costs were obtained from a variety of sources at LLNL. The costs of demonstration were based upon overall funding received from the Department of Energy, program management planning documents, capital costs for individual equipment components, and actual operating costs incurred during the second steam pass (which is most representative of operating costs for future applications).

• LLNL has prepared an estimate of potential cost savings if DUS were applied at the same site in the future with the benefit of lessons learned and without research-oriented activities. **Resultant total savings would be approximately $4,000,000 or a 40% reduction versus demonstration costs.**

Overall Program Costs

Construction through 1st Steam Pass	$7.240M
2nd Steam Pass	2.200M
ARV Phase	1.000M
Total	$10.440M

Note: Costs include all research and development costs associated with the demonstration

Identified Cost Components

The following program elements were taken from planning documents.

Project Management

Management	$225,000
Analysis and report writing	335,000
Safety plan writing and review	70,000
Permitting	65,000
Equipment design	200,000
	$895,000

Process Monitoring

Design	$50,000
ERT and thermal	270,000
Tiltmeter	70,000
Hydraulic testing	55,000
	$445,000

Characterization and Compliance Monitoring

Drilling-phase sampling	$315,000
Pre-electrical heating sampling	35,000
Pre-steam sampling	20,000
Post-steam sampling (4 new wells)	50,000
Compliance monitoring	10,000
Sampling during experiment	25,000
	$455,000

Demonstration Costs (continued)

Identified Cost Components (continued)

The following capital cost items include overlaps with the program cost elements shown previously:

Subsurface Wells

Note: Costs do not include design and installation labor

Steam injection/vapor extraction (8 wells at approx. \$32,000 each with average depth of 145 ft)	\$256,000
ERT-Temperature monitoring (11 wells at approx. \$10,000 each with average depth of 165 ft)	\$110,000
Electrical heating (3 wells at approx. \$10,000 each with average depth of 120 ft)	\$30,000

Electrical Heating Surface Equipment

Note: *Costs do not include design and engineering*

Installation labor	\$129,000
Transformer	50,000
Circuit breaker/switch panel	40,000
Cable	18,000
Miscellaneous materials	67,000
Other direct costs	63,000
	\$367,000

Steam Generation Surface Equipment

Note: Boiler leased for \$17,300/month; design costs not included

Installation labor	\$174,000
Boiler utility set-up	100,000
Miscellaneous materials	42,000
Other direct costs	79,000
	\$395,000

Extracted Ground Water and Vapor Surface Treatment Systems - Treatment Facility F

Note: Costs do not include design and engineering; facility originally designed for 30-year pump-and-treat mission

Piping and power	\$1,512,000
Process equipment	400,000
Vapor modifications for DUS	160,000
Discharge pipeline	87,000
Activation	80,000
Other direct costs	291,000
	\$2,530,000

Operating Costs

Utility Consumption

Boiler natural gas (3 8E10 ft^3 @ \$0.39/100,000 ft^3)	\$149,000	\$1.50/yd^3 treated
Boiler water (3 6E6 gal @ \$1.25/100 ft^3)	\$6,000	
Boiler electricity (40,000 kWh @ \$0.06/kWh)	\$2,400	
Electricity for electrical heating (200,000 kWh @ \$0.06/kWh)	\$12,000	

Labor and Material Costs for 2nd Steam Pass **(all values in thousands of dollars)**

Note: Costs represent 6 weeks of 24-hr operations and continuously monitored experimental conditions

	Scientists and Engineers	Technicians	External Analysis	Materials	TOTALS
Phase 1: Planning	44	-	-	-	44
Phase 2: Maintenance and Modification	2	31	-	27	60
Phase 3: Operations					
Steam Injection Operations					
Periods of steam injection	27	51	-	167	245
Periods of no steam injection	14	5	-	-	19
ERT Monitoring	13	22	-	-	35
Additional UC Berkeley support	-	50	-	-	50
Effluent Treatment Operations					
Effluent treatment	35	203	-	91	329
Sampling and analysis	50	17	18	-	85
Phase 4: Post Steaming Characterization					
Sampling	41	36	-	-	77
Soil Analysis	-	-	83	-	83
Drill Rig	-	26	-	9	35
Phase 5: Reporting and Technology Transfer	400	-	-	-	400
Phase 6: Dismantling (conservative estimate)					181
Contingencies					228
				Grand Total	***\$1,871***

Cost Considerations for Future Applications

Cost Savings for Commercial Applications

• LLNL has prepared an estimate of potential cost savings if DUS were applied at the same site in the future with the benefit of lessons learned and without research-oriented activities. The estimated savings would be derived from:

- reduction in design effort by over 50% (-$206K)
- elimination of discharge lines & transformer modifications (-855K)
- use of temporary steam generation equipment (-355K)
- reduced site characterization (-210K)
- replacement of UV unit with air stripper (-500K)
- elimination of modification designs for 2nd pass steam and ARV phases (-604K)
- reduced management effort (-100K)
- reduced science & engineering staff requirements (-166K)
- reduced operations staff requirements (-505K)
- reduced reporting and safety documentation preparation (-470K)

Resultant total savings would be approximately $4,000,000 or a 40% reduction versus demonstration costs

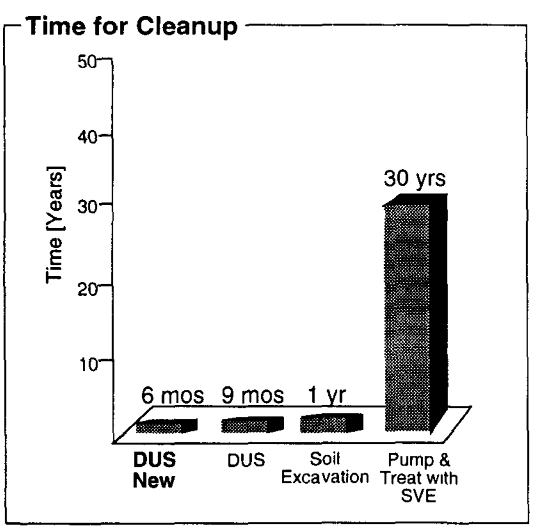
Cost Estimates Completed for Additional Applications

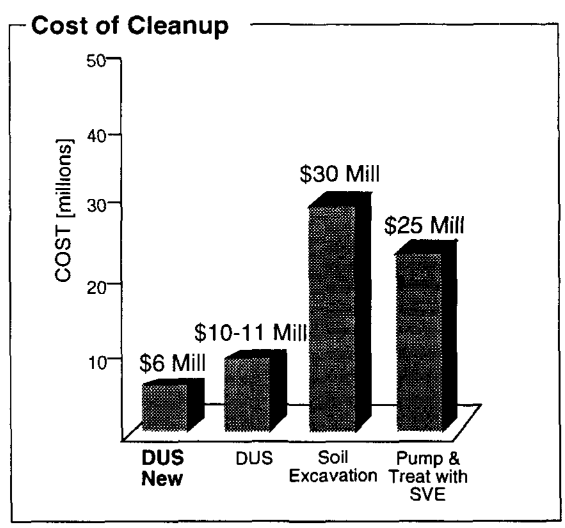
• LLNL researchers prepared a cost estimate for applying DUS to a shallow chlorinated solvent spill at the DOE Pinellas facility. Key results of that cost estimate were:

- average cleanup costs of approximately $65/yd3 which was based upon a fixed cost of approximately $1.5 M and a variable cost of $20/yd^3 indicated the increased cost-effectiveness of the technology at larger sites
- a total cost for DUS implementation was estimated as less that the first year cost of constructing and operating a conventional groundwater pump and treat facility

Cost Savings Versus Alternative Technologies

DUS costs and remediation times were compared, by LLNL researchers, to estimated costs and cleanup times of applying alternative technologies at the GSA:





Notes: DUS New = cost of commercial application of DUS at the GSA as outlined at top of page
DUS = cost of demonstration program for DUS
Soil Excavation includes relocation of underground utilities
SVE = soil vapor extraction

APPENDIX F

REFERENCES

Major References for Each Section

Demonstration Site Characteristics:	Source (from list below) 1 and 17
Technology Description:	Source 1, 4, 6, 7, 8, 9, 10 and 11
Performance:	Source 1, 2, 4, 6, 7, 8, 9, 10, 11, 13, 14,15 and 18
Cost:	Source 1, 3 and 18
Regulatory/Policy Issues:	Source 1, 6, 8, 9, 14 and 15
Lessons Learned:	Source 1, 2, 6, 7, 8, 9, 10, 11, 13, 14, 15, and 18
Commercialization:	Source 1, 5, 8, 12 and 16

Chronological List of References and Additional Sources

1. Personal communications with Roger Aines, Lawrence Livermore National Laboratory, (510) 423-7184, November 1994-January 1995.

2. Personal communications with Marina Jovanovich, Lawrence Livermore National Laboratory, (510) 422-2144, January 1995.

3. Memorandum from Roger Aines, LLNL to Jesse Yow, LLNL, "Summary of Dynamic Underground Stripping Funding," December 19, 1994.

4. Personal communications with Robin Newmark, LLNL, (510) 423-3644, November 1994.

5. U.S. Environmental Protection Agency, *Superfund Innovative Technology Evaluation Program: Technology Profiles Seventh Edition,* EPA/540/R-94/526, November 1994.

6. *Design, Construction and Operation of the Dynamic Underground Stripping Facility at Lawrence Livermore National Laboratory,* draft, Lawrence Livermore National Laboratory, Livermore, CA, 1994.

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12. MacDonald, J.A., and M.C. Kavanaugh, "Restoring Contaminated Groundwater: An Achievable Goal?", *Environmental Science & Technology,* Vol. 28, No. 8, August 1994.

F

Chronological List of References and Additional Sources (continued)

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17. Bishop, D.J. [ed.], *Dynamic Underground Stripping Characterization Report*, draft, Lawrence Livermore National Laboratory, Livermore, CA, January 1994.

18. Brown, Mike, Roger Liddle, Alan Copeland, and John Ziagos, "Headquarters Dynamic Underground Stripping Briefing," presentation materials, October 1993.

This summary was prepared by.

CKY incorporated
Environmental Services
140 E Division Rd Suite C-3
Oak Ridge, Tennessee, 37830
Contact. Kenneth Shepard (615) 483-4376

in conjunction with:

Stone & Webster Environmental Technology & Services
245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

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LAWRENCE LIVERMORE NATIONAL LABORATORY
ENVIRONMENTAL TECHNOLOGY PROGRAM
EARTH SCIENCES DIVISION
which supplied key information and reviewed report drafts
Final editing and production was provided by the
Colorado Center for Environmental Management
999 18th Street Suite 2750
Denver CO 80202
(303) 297-0180

for:

HAZWRAP

HAZARDOUS WASTE REMEDIAL ACTIONS PROGRAM
Environmental Managment and Enrichment Facilities
Oak Ridge, Tennessee 37831-7606
managed by
MARTIN MARIETTA ENERGY SYSTEMS
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950R-7400-001-008

Pump & Treat of Contaminated Groundwater at Operable Unit B/C McClellan Air Force Base California (Interim Report)

Case Study Abstract

Pump & Treat of Contaminated Groundwater at Operable Unit B/C McClellan Air Force Base, California

Site Name: McClellan Air Force Base, Operable Unit (OU) B/C **Location:** Sacramento, California	**Contaminants:** Chlorinated Aliphatics - Trichloroethene (TCE), cis-1,2-Dichloroethene (cis-1,2-DCE), Tetrachloroethene (PCE), 1,2-Dichloroethane (1,2-DCA) - In an area of 7,800 million cubic feet, there is an estimated 33,000 kg of VOCs; percent of total mass for individual constituents is TCE (82.7%), cis-1,2-DCE (0.5%), PCE (16.7%), 1,2-DCA (0.1%)	**Period of Operation:** Status: Ongoing Report covers - 1988 to 1993 **Cleanup Type:** Full-scale cleanup (interim results)
Vendor: Not Available **SIC Code:** 9711 (National Security)	**Technology:** Groundwater Extraction followed by Aboveground Air Stripping - 7 extraction wells pump to a main treatment plant - Air stripper - design capacity of 1,000 gpm; average flow rate of 250 gpm - Supplemental Treatment - thermal oxidizer and caustic scrubber for offgases; two GAC units in series to polish liquid phase prior to discharge	**Cleanup Authority:** DoD **Point of Contact:** Remedial Project Manager McClellan AFB Sacramento, CA
Waste Source: Landfill; Underground Storage Tank; Disposal Pit; Open Burn Area **Purpose/Significance of Application:** Full-scale remediation of groundwater contaminated with VOCs using groundwater extraction and aboveground air stripping.	**Type/Quantity of Media Treated:** Groundwater - As of 1/94: Over 660 million gallons of groundwater treated since startup in March 1987 - Groundwater subsurface consists of 5 distinct monitoring zones (A through E); evidence points to hydraulic link among 5 zones - Hydraulic conductivity ranges from 2.8 to 30.7 ft/day - Transmissivity ranges from 100-2,000 ft^2/day	
Regulatory Requirements/Cleanup Goals: Final cleanup criteria have not been established at this time - Current target is <0.55 µg/L VOCs for groundwater - NPDES permit - acetone, MEK, and MIK to <1 mg/L and VOCs to <0.5 µg/L		

Pump & Treat of Contaminated Groundwater at Operable Unit B/C McClellan Air Force Base, California (Continued)

Results:
- Influent VOC concentrations have decreased from about 60 ppm in 1987 to about 4 ppm in 1993
- The effluent from the treatment system has been below the permitted discharge levels since operation began
- As of 3/94, approximately 44,000 lbs of VOCs have been removed since startup

Cost Factors:
- Total Capital Cost in 1987 - $4,000,000 (including over $1,700,000 for the incinerator, air stripper, scrubber, wells, and GAC tanks, and about $1,000,000 for heat exchangers, blowers, pumps, and compressors; control center)
- Total Annual Operating Costs - $1,240,000 (including contractor operations, utilities, sampling and analysis, project management)
- An estimated total cost for completing the cleanup is not available at this time

Description:
The McClellan Air Force Base in Sacramento, California was established in 1937. Operations at the 3,000-acre facility include aircraft, electronics, and communications equipment maintenance and repair, and a wide variety of hazardous materials have been used at the site. The site was added to the National Priorities List in 1987. Areas of contamination at the site include Operable Unit B (OU B) and Operable Unit C (OU C). Releases from OU B resulted from disposal/release of hazardous substances from landfills, underground storage tanks, storage lots, burial and burn pits. Releases from OU C were attributed to waste disposal activities. Extensive VOC contamination has been identified at the facility. The primary constituents of concern are TCE, cis-1,2-DCE, PCE, and 1,2-DCA.

A groundwater extraction and treatment system including air stripping was installed with operations beginning in 1988. Offgases from the air stripper are treated by thermal oxidation and caustic scrubbing. The effluent from the air stripper is treated using GAC prior to a NPDES-permitted discharge. The 1993 data on the influent to the air stripper show that the VOC concentrations have decreased to about 4 ppm from concentrations of 60 ppm (1987). An estimated 44,000 pounds of VOCs have been removed as of March 1994. The remediation was ongoing at the time of this report and final performance data are not yet available. In addition, the treatment system has been effective in treating groundwater to below the NPDES discharge limits.

The total capital costs for this system are $4,000,000 and the total annual operating costs are $1,240,000. The system has been on line 98% of the time. Problems of scaling and deposition in the air stripper from calcium and magnesium salt precipitation were remedied by changing to 2-inch packing from 1-inch packing in the air stripper. Corrosion was minimized through material changes to nickel-based commercial alloys and change in physical layout to improve flow.

TECHNOLOGY APPLICATION ANALYSIS

SITE

McClellan Air Force Base
Groundwater Operable Unit (OU) B/C
Sacramento, California

TECHNOLOGY APPLICATION

This analysis covers an effort to pump and treat groundwater contaminated with volatile organic compounds (VOCs) by above ground air stripping. The treatment began in 1988, was expanded in 1990 and is ongoing. This analysis covers performance through 1993.

SITE CHARACTERISTICS

Site History/Release Characteristics

- McClellan Air Force Base (AFB), an Air Force Command Logistics Center, was established in 1937. Operations have included the management and repair of aircraft, electronics and communications equipment. These activities have involved the use, storage and disposal of a wide variety of hazardous materials such as petrochemical solvents, cleaners, electroplating chemicals, heavy metals, polychlorinated biphenyls (PCBs), low-level radioactive wastes and fuel oils and lubricants.
- In 1987, the base was placed on the National Priorities List as the highest priority U.S. Air Force Installation.
- Investigations of groundwater contamination beginning in 1979 have identified three areas containing VOC plumes onbase and offbase. Overall contamination at 254 confirmed and potential sites have been grouped within 11 OUs.
- Base operations within OU B resulted in the disposal or environmental release of a wide variety of hazardous materials at landfills, underground storage tanks, storage lots, burial pits and burn pits. The primary nature of base activities within OU C was waste disposal. The Industrial Waste Line (IWL) conveyed wastes from numerous facilities to OU B and C and is itself a major source of contaminant releases.

Contaminants of Concern

The primary contaminants of concern (listed in order of frequency of detection) are:.

Trichloroethene	(TCE)
cis-1,2-Dichloroethene	(cis-1,2-DCE)
Tetrachloroethene	(PCE)
1,2-Dichloroethane	(1,2-DCA)

Contaminant Properties

Property at STP*	Units	TCE	cis-1,2-DCE	PCE	1,2-DCA
Empirical Formula	-	$ClCH{=}CCl_2$	$CHCl{=}CHCl$	$Cl_2C{=}CCl_2$	$C2H_4Cl_2$
Density	g/cm^3	1.46	-	1.62	126@15°C
Vapor Pressure	mmHg	59	200	14	64
Henry's Law Constant	$atm{\cdot}m^3/mole$	8.9E-3	7.5E-3	2.3E-2	1.1E-3
Water Solubility	mg/L	1,000	3,500	150	8,690
Octanol-Water Partition Coefficient; K_{ow}	-	240	5	398	3
Organic Carbon Partition Coefficient; K_{oc}	-	126	32	661	14

**STP = Standard Temperature and Pressure; 1 atm, 25 °C*

Nature & Extent of Contamination

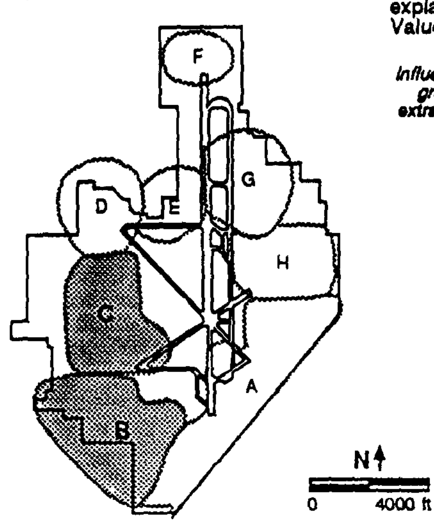
- Contaminants in groundwater have been found to exist in 3 separate phases at McClellan: sorbed to the soil matrix, solubized in porewater, or as free product. Contamination is additionally present dissolved in soil gas in the vadose zone.
- A drop in groundwater levels of 60 feet over the past 50 years has created a smear zone of contamination above the declining water table.
- In general, the concentrations of VOCs of concern in groundwater has decreased with time while the number of monitoring wells detecting the contaminants has increased.

Contaminant Locations and Geologic Profiles

Over 300 monitoring wells and 14 extraction wells have been installed basewide. In 1986, an extensive monitoring program was initiated to assess levels of volatiles, semivolatiles, metals, pesticides and dioxins. A small portion of this hydrogeologic and contaminant location data has been included here to provide a general understanding of site conditions.

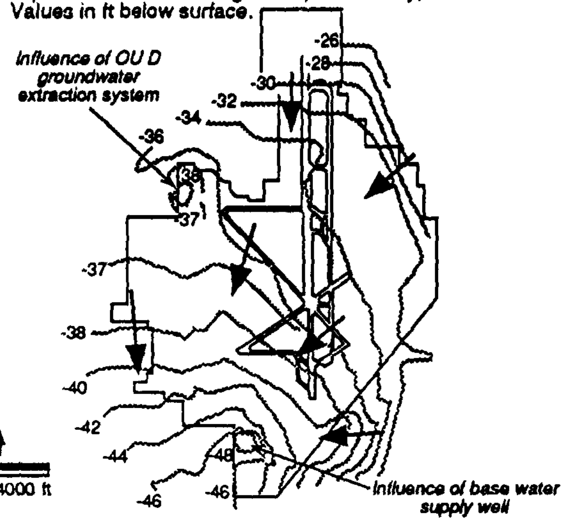
Site Layout

Operable Unit locations



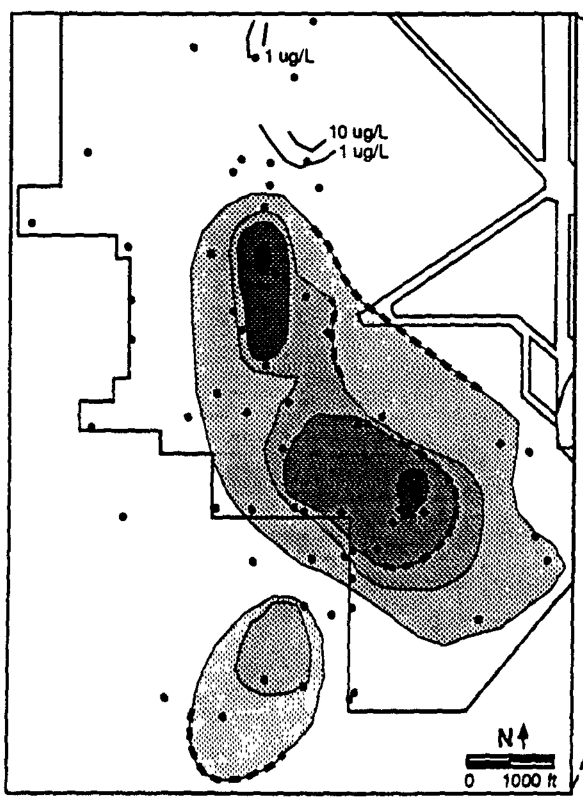
Groundwater Levels & Flow Directions

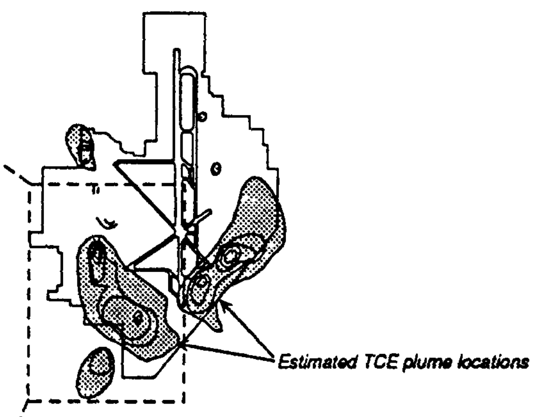
Data from groundwater monitoring Zone A (see p. 3 for explanation of monitoring zones) in January, 1993. Values in ft below surface.

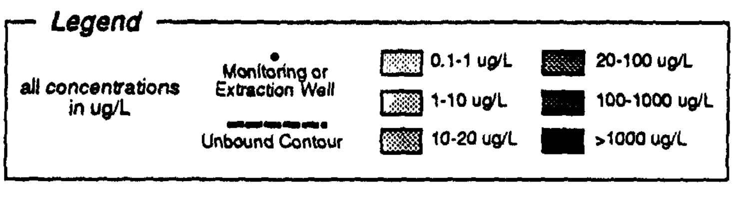


TCE Plume

Data from groundwater monitoring Zone A in 1993.







- TCE concentrations are highest near confirmed source areas; horizontal movement of contamination is limited, and is in a southwest direction.
- TCE concentrations are much higher in the A monitoring zone than the B,C,D or E zones which suggest that downward migration has been slowed by operation of the pump and treat system.
- Locations of other VOCs of concern are generally similar to TCE locations.
- *Overall amounts of VOCs of concern present in groundwater ar McClellan has been estimated at 33,000 kg occupying over 7800 million ft 3 with the following breakdown:*

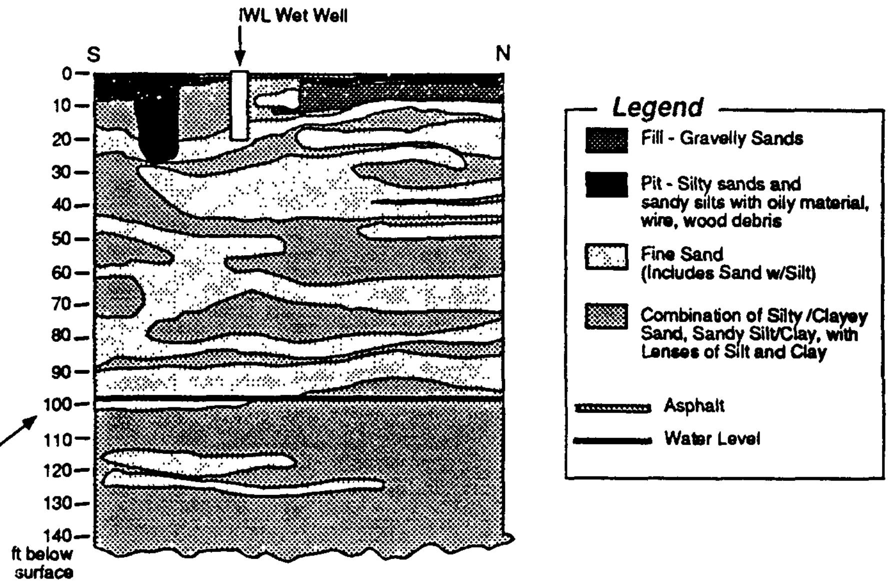
Contaminant of Concern	Monitoring Zone %A	%B	%C	% of Total Mass
TCE	38	42	20	82.7
cis-1,2-DCE	44	29	27	0.5
PCE	40	60	0	16.7
1,2-DCA	92	8	<1	0.1

Contaminant Locations and Geologic Profiles (Continued)

Hydrogeologic Profile

- Soils and geology at the base are a complex series of alluvial and fluvial deposits which were deposited, eroded and redeposited.
- Deposits of any one lithology are limited in horizontal and vertical extent; units rarely extend laterally for more than 50 ft.
- Extensive subsurface characterization has been performed to depths over 400 ft. below the surface which has aided understanding of the relative permeabilities of subsurface materials beneath each operable unit and within each monitoring well zone.

Soil boring data taken from a north-south cross section illustrates typical conditions beneath source area waste pits and the industrial waste line.



Site Conditions

- McClellan Air Force Base occupies nearly 3,000 acres and is located approximately 7 miles northeast of downtown Sacramento. Land use immediately adjacent to the base includes residential areas supplied by private well water for nonpotable uses. (Connection of residences west of the base to municipal rather than private water supplies was a remedial action initiated by the base in the late 1980s.)
- Topography is generally flat and sloping gently from the east side at 75 ft mean sea level (MSL) to the west side at 50 feet MSL.
- Climate is characterized by hot, dry summers and cool, moist winters with average annual temperature of 60° F and precipitation of 17 inches.
- Regional groundwater levels have dropped over 60 ft in the last 50 years, including a drop rate of 1.5 to 2 ft/yr for the past 10 years, due to pumping for agricultural irrigation, domestic use and base use.

Key Aquifer Characteristics

- The groundwater subsurface has been divided into five distinct monitoring zones (A, B, C, D and E) layered atop one another. However, there is strong evidence that the units are hydraulically linked. Each of the highly heterogenous zones have similar water levels, flow directions, vertical gradients and concentrations of inorganic species.
- Groundwater quality is characterized as a calcium-sodium-bicarbonate type excellent for irrigation and domestic use.
- Flow direction is mainly south in OU B/C in the A, B and C zones and is significantly influenced by a base water supply well in OU B. The supply well draws water at a rate of 1200 GPM from several screened depths up to 400 ft.
- Other key aquifer parameters have been estimated as

Zone	A	B	C
Transmissivity (ft^2/day)	100-900	250-500	500-2,000
Hydraulic Conductivity (ft/day)	2.8-25.7	3.8-7.7	7.7-30.7
Zone Thickness (ft)	35	65	65

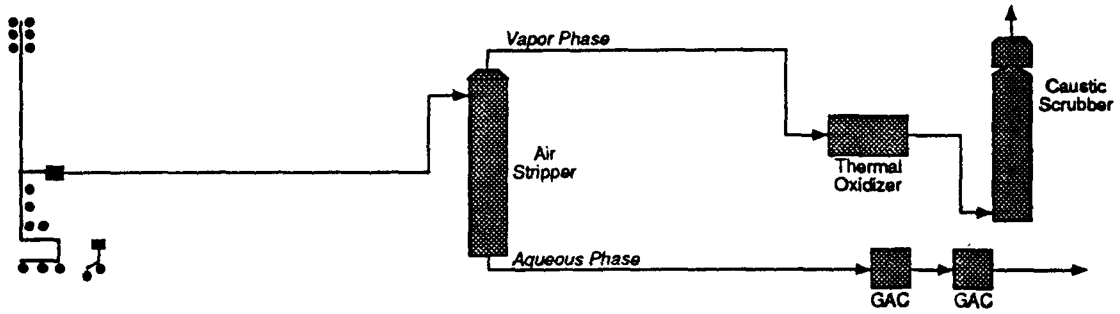
- Other physical characteristics of the aquifer materials were measured during a series of basewide remedial investigations:

Parameter	Range
Organic carbon content, foc:	0.001 to 0.003
Moisture content, wet percent:	0.25 to 0.25
Porosity:	0.35 to 0.45
Bulk density, g/cm^3:	1.2 to 1.3

TREATMENT SYSTEM

Overall Process Schematic

Extraction Well Network — **Treatment Plant and Permitted Discharge**

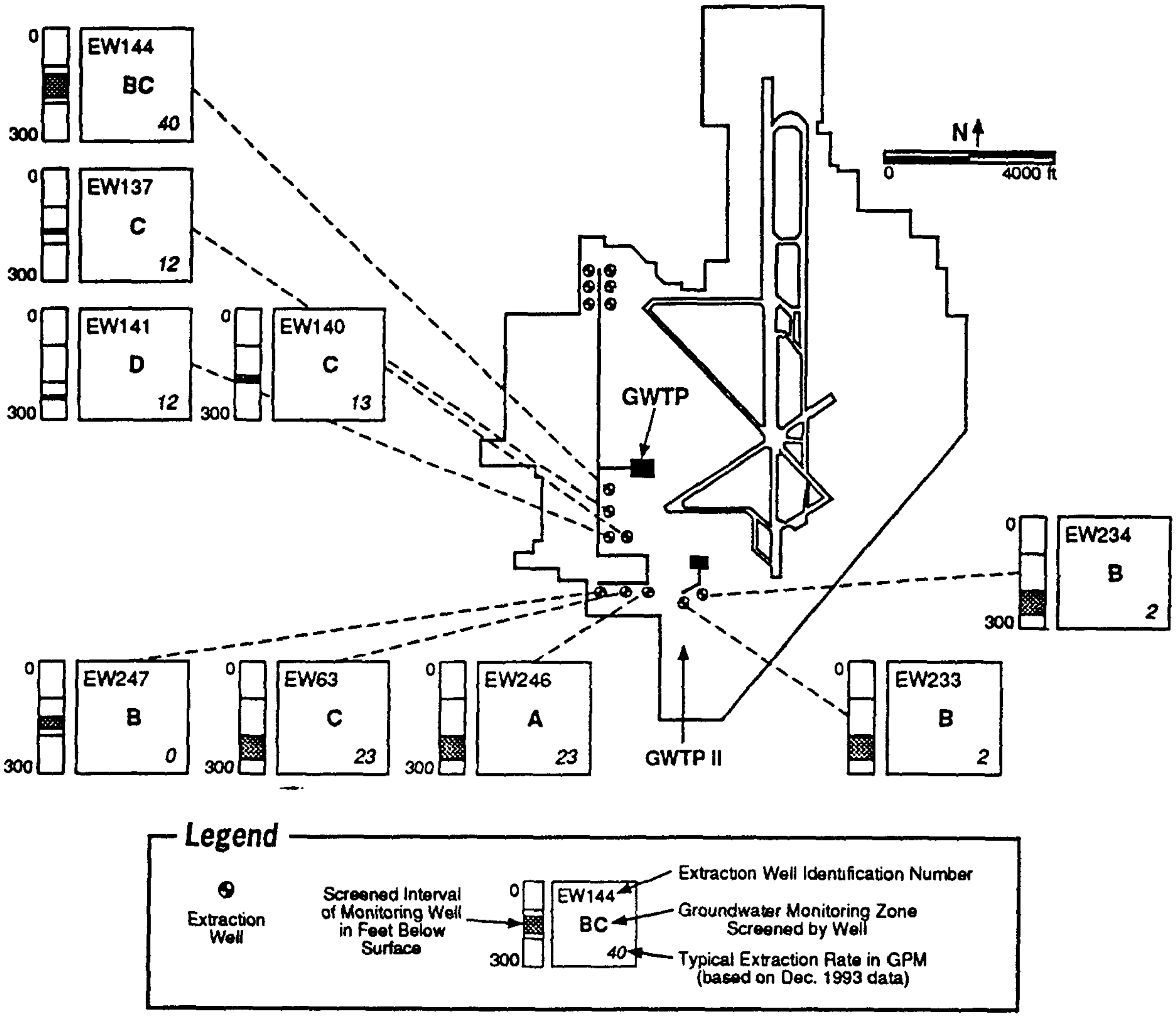


7 extraction wells within OU B/C pump water to a centralized treatment plant.
2 wells pump water to a small treatment unit within OU B

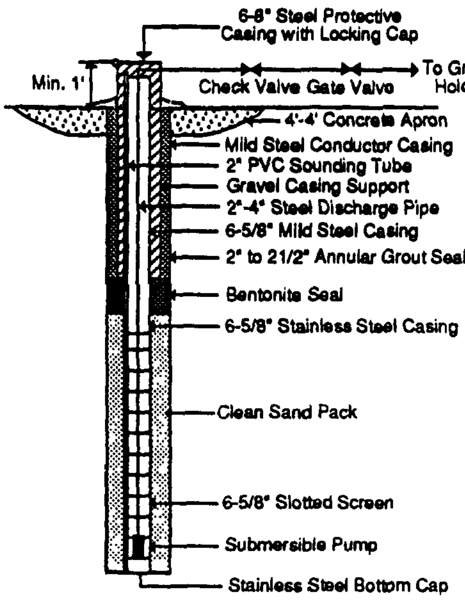
The main treatment plant with a capacity of 1000 GPM treats an average flow rate of 250 GPM by air stripping

Offgases are thermally treated and scrubbed before release to the atmosphere. Liquid effluent is polished by granular activated carbon (GAC) before discharge to a nearby stream.

Extraction Well Network



Extraction Well Detail

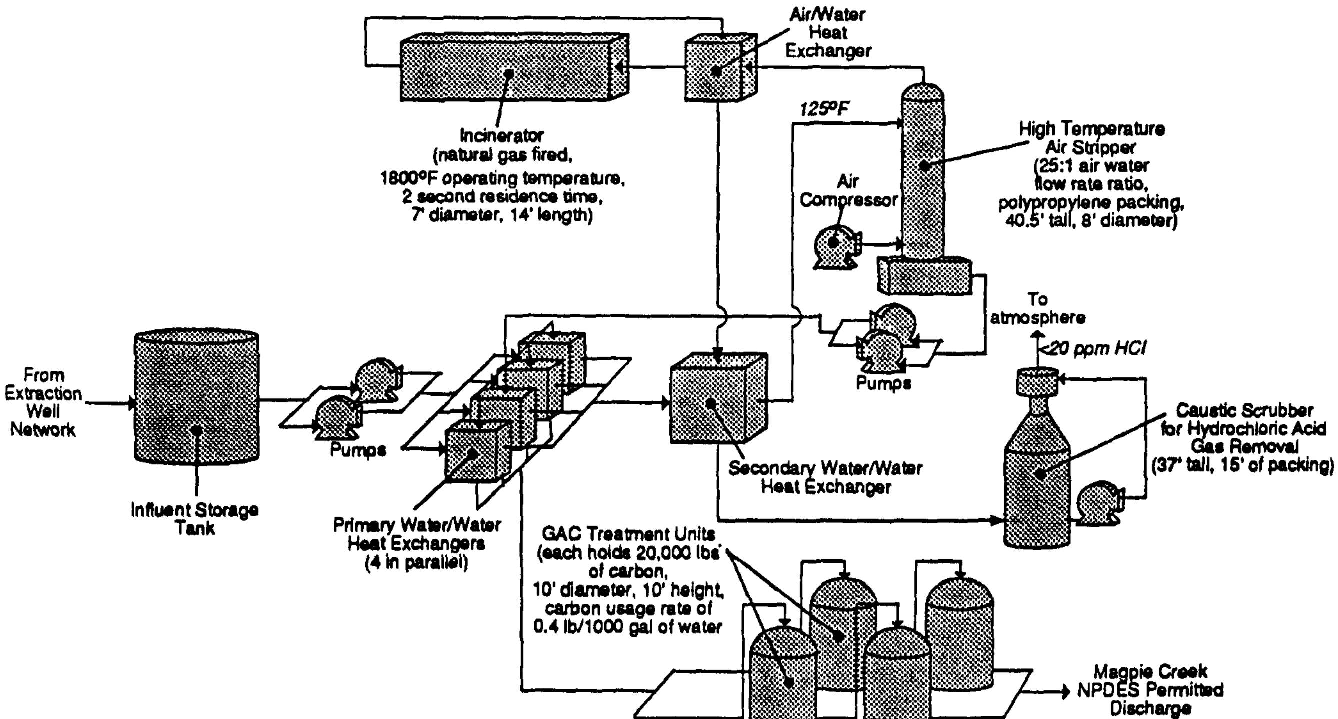


Design Evolution

The GWTP has undergone several significant redesigns. The current configuration presented below reflects changes made to minimize scaling problems in the configuration of heat exchangers as well as to accommodate lower influent flow rates and VOC concentrations. The configuration shown has been used for all but few months of the GWTP operation. Specific design changes have included:

- Introduction of recycle loops to allow air stripper operation at lower than originally anticipated flow rates. The original design was based upon an influent stream of 1000 GPM while actual rates have ranged from 100 to 250 GPM.
- Reduction in maximum system water temperature from 188°F to 120°F as a result of improved internal recycling of aqueous streams.
- Replacement of carbon steel air-water heat exchanger with nickel-based commercial alloy equipment to decrease susceptibility to corrosion from acid gas condensation.
- Rearrangement of heat exchange network to reduce susceptibility of scaling from precipitation of calcium and magnesium salts.
- Replacement of air stripping packing material to a medium with larger void space to reduce susceptibility of fouling from scaling buildup.
- Elimination of activated sludge treatment process for kerosene removal, which followed the granular activated carbon (GAC) treatment, once influent ketone concentrations fell below detection limits.

Treatment System Schematic



- The plant operates 24 hours/day, 365 days/year and is staffed by 4 full time employees working two 12 hour shifts and 1 part time secretary. At least one operator is on duty at all times.
- The plant has full spare backup pumps and blowers and backup GAC and heat exchange capacity at low flow rates.
- GWTP II which operates within OU B is a simple arrangement of two groundwater extraction wells pumping approximately 2 GPM each through a double-contained pipeline equipped with a leak detection system to a holding tank. The groundwater is then pumped through a bag filter and treated by two GAC adsorption units in series.

PERFORMANCE

Performance Objectives

A primary objective of the GWTP and its associated extraction well network within OU B/C is to limit the offbase subsurface migration of contamination plumes beneath the OU.

Additional groundwater operable unit priorities include:

- Control of concentrated areas of contamination or hot spots.
- Remediation of contamination between the hot spots and plume boundary.

Remedial Action Plan

The remediation strategy for OU B/C includes:

Ongoing

Pumping and treatment of groundwater to prevent further migration of pollutants. This effort is the focus of this analysis.

Future

- Continued implementation of existing technologies and possible upgrade to accommodate higher flow rates of contaminated groundwater from other areas on the west side of the base. A similar treatment plant is proposed as a remedial alternative for the east side.
- Incorporation of innovative technologies within current efforts particularly to address hot spot (>500 ug/L VOCs) areas. These technologies include in situ anaerobic biodegradation, soil vapor extraction with air-sparging, cometabolic treatment, and dual-phase extraction.

Operational Performance

As of January 1994 the GTWP had treated over 660 million gallons of groundwater since startup in March 1987.

During 1993 the GWTP:

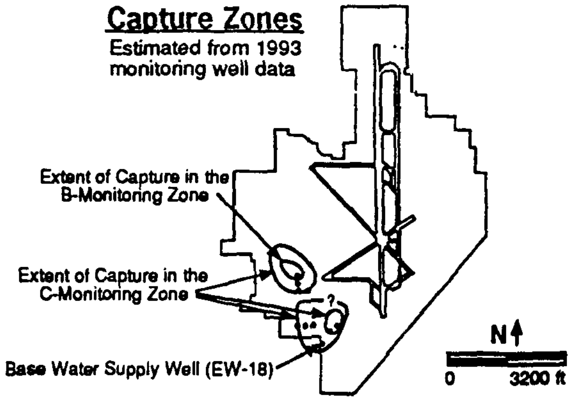
- Treated over 73 million gallons of groundwater
- Was online 98% of all available time
- Experienced 2 major repairs
- Experienced 9 minor repairs
- Consumed 2.2 million ft^3 of natural gas, 200,000 kwhrs of electricity, approximately 650 gallons of sodium hypochlorite, and over 50 gallons of sodium hydroxide

GWTP II had processed a total of 7.9 million of groundwater as of January 1994 and had only one minor repair during 1993 which allowed for a 98% total system uptime percentage.

Hydrodynamic Performance

• Within OU B the five existing extraction wells pump water either to the GWTP or the local carbon treatment unit (GWTP II). In addition, a base water supply well is located within OU B and creates a radius of influence of approximately 500 to 700 ft in the A and B zones and a slightly higher influence in the C zone due to a larger screened interval.

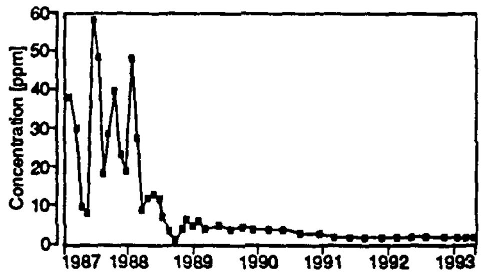
• The four extraction wells in OU C capture approximately 90 GPM from the A, B and C zones but do not contain the known groundwater contamination areas.



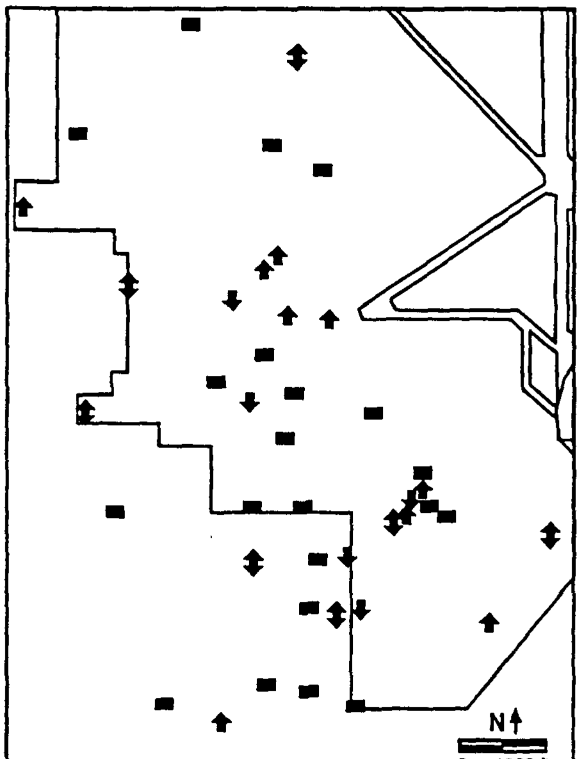
Treatment Performance

Influent & Effluent Data

• The concentrations of contaminants in the GWTP influent has varied over short time periods but has exhibited a significant downward trend since startup.
• Influent VOC concentrations were approximately 60 ppm in 1987 and have decreased to approximately 4 ppm.
• The GWTP has consistently removed VOCs to below established discharge criteria for primary contaminants since startup.
• Over 44,000 lbs of VOCs have been removed since startup.



Effects on Plume



Close-up of OU B/C area identified on page 2.

• A comparison of individual monitoring well data from 1986 to 1993 was performed to determine trends in VOC concentrations.

• Monitoring Zone A: Most wells exhibited static trends. There is no observable overall trend for OU B wells. More wells within OU C than OU B exhibit increasing trends which may indicate continued contaminant release from the vadose zone to OU C.

• Monitoring Zones B through D: Most data is static which may suggest that groundwater impacts within the deeper zones are equilibrated. OU B data within the B and D zones presents much uncertainty. Zone C shows more increasing wells which, in the case of OU C, may represent preferential migration from other OUs.

Legend
- ■ Wells with constant risk values
- ↑ Wells with increasing risk values
- ↕ Wells with fluctuating risk values
- ↓ Wells with decreasing risk values

COST

• The groundwater extraction and treatment system at McClellan was built in several phases from the late 1980's to early 1990s. The data below was provided by McClellan personnel based upon available records. Pump and treat efforts have removed over 42,000 pounds of VOCs at the base as of March 1994. This corresponds to dollars per pound removal rates of approximately $80/lb VOC based on operating costs alone (based upon an analysis done with first year operation data) and approximately $150/lb VOC including treatment system direct costs. Cost bases and assumptions are detailed below:

Capital Costs

Direct Costs	
Incinerator	$300.000
Air Stripper	400,000
Scrubber	300,000
Water to Water Heat Exchanger	200,000
Gas to Water Heat Exchanger	50,000
Gas to Gas Heat Exchanger	50,000
Electric Motors (6)	180,000
Blowers (2)	40,000
Pumps (6)	180,000
GAC Tanks (4)	360,000
Water Holding Tank	40,000
Berm and Foundation	150,000
Air Compressors (2)	60,000
Water Pipes to Plant	300,000
Wells and Pumps (10) (a)	300,000
Control Center and Trailer	80,000
Control Center External	60,000
Subtotal Direct Costs	3,090,000
Indirect Costs	910,000
Total Capital Cost in 1987 (b)	**$4,000,000**

Operating Costs

Contractor Operations	
Labor	$300,000
Operation Support	350,000
Reimbursables	200,000
Other Direct Costs	150,000
Utilities	
Electricity for Extraction Wells	30,000
Electricity for Treatment Plant	50,000
Natural Gas	40,000
Sampling and Analysis	40,000
McClellan Staff Labor	80,000
Total Annual Operating Costs	**$1,240,000**

(a) Three additional extraction wells were added within the OU B in 1990. McClellan estimates the cost of developing and extraction well at the site to be approximately $100,000.

(b) The small treatment plant within OU B was constructed in 1991 for a total cost of approximately $1,000,000 broken down as follows (Numbers taken from an estimate prepared while construction was ongoing and all values rounded to the neared multiple of $5,000):

Direct Costs	
Extraction/Monitoring Wells	$145,000
Piping and Fittings	55,000
Pumps	10,000
Holding Tank	15,000
GAC Treatment Units	60,000
Discharge Piping and Fittings	5,000
Contaminated Soil Disposal	95,000
Site Work (@25%)	100,000
Piping/Valving (@5%)	20,000
Instrumentation (@5%)	20,000
Controls (@5%)	20,000
Electrical (@15%)	60,000

Indirect Costs	
Contingency (@5%)	30,000
Fees (@15)	90,000
Construction Management (@15%)	90,000
Startup (@10%)	60,000
Sampling (@10%)	61,000

The yearly operating costs of the system is approximately $70,000 and is largely for GAC replacement.

REGULATORY/INSTITUTIONAL ISSUES

• The GWTP currently has a National Pollution Discharge Elimination System (NPDES) which permits a 0.36 MGD discharge with a total allowable discharge of 1.45 MGD (30-day average) from additional groundwater extraction systems.

• The NPDES permit for the GTWP sets forth sampling requirements and limitations for discharge into Magpie Creek, an onbase stream. The primary treatment requirements are that the plant remove acetone, methyl ethyl ketone and methyl isobutyl ketone to less than 1 mg/L, and remove all other VOCs to less than 0.5 ug/L.

• Air permits from the Sacramento Metropolitan Air Quality Management District require sampling and specify certain operation conditions and procedures. A risk assessment of the facility was performed as part of the permitting process

• McClellan AFB has developed positive working relationships with federal and state environmental regulators which has facilitated planning and implementation of remedial measures.

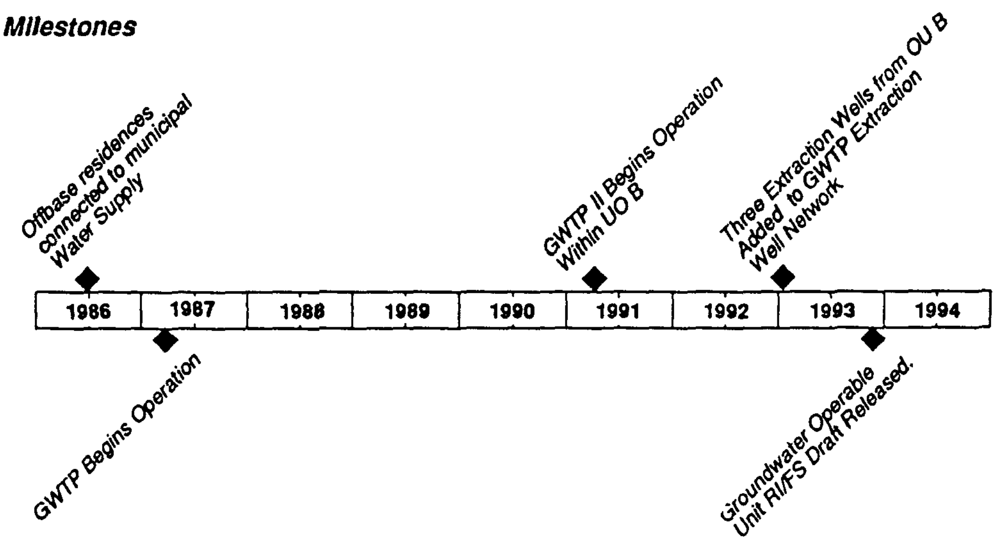
• McClellan AFB has extensive ongoing public involvement programs which have been instrumental in overcoming initial apprehensions about the GWTP.

Cleanup Criteria

• While final cleanup criteria have yet to be determined for groundwater beneath Operable Units B and C, treatment requirements mandate removal of the principle VOCs of concern to less than 0.55 ug/L. The base and regulators are currently evaluating cleanup scenarios based upon remediation to Maximum Contaminant Levels (MCLs), lifetime individual cancer risk levels less than 1E-6 (more stringent), or background levels (most stringent).

SCHEDULE

Major Milestones



LESSONS LEARNED

Design and Implementation Considerations

• Major changes in the quantity of extracted groundwater and changes in VOC influent concentrations have necessitated changes in GWTP design and operation. Currently the plant has excess treatment capacity requiring internal recycle of groundwater to sustain efficient treatment which raises operating costs. These and other process changes have optimized performance at lower flow rates.

• Existing extraction systems at McClellan capture a small portion of the groundwater contamination present at the site. The system must be significantly expanded to create a zone of capture encompassing other known areas of contamination. The success of the existing design has established it as a candidate system of choice for future remediation efforts.

• Scaling and deposition within the air stipper from precipitation of calcium and magnesium salts affected initial operation. The problem was minimized by substituting 2 inch packing for 1 inch packing in the air stripper.

• Corrosion was observed in the hot vapor train due to condensation of acid gases. The problem was minimized through both substitution of materials of construction from carbon steel to nickel-based commercial alloys and changes in physical layout which reduced turbulence, improved laminar flow and eliminated stagnant regions.

Technology Limitations

• Influent concentrations to the treatment plant have shown a significant downward trend since startup, however, that trend has stabilized in recent years. Groundwater monitoring data largely exhibits static trends in VOC concentrations despite the removal of over 40,000 lbs of VOCs from OUs B/C and OU D.

• Among the organic compounds being treated, acetone is the only compound that the air stripper has had difficulty removing because of its solubility in water. Biological treatment was initially required but has been discontinued after acetone was no longer encountered in the GWTP influent.

• Pump and treat efforts at McClellan must be augmented with vadose zone source area remediation efforts so that continued seepage of contamination into groundwater does not require indefinite pump and treat operation.

Future Technology Selection Considerations

• Pump and treat efforts have been successful at containing further migration of contamination. Only low concentrations of VOCs are anticipated to migrate beyond the established zones of control.

• The above ground treatment system has been effective at consistently reducing VOC levels below discharge criteria.

• The air stripper/incinerator/scrubber treatment train has proven to both efficient and effective.

• Although incineration has proved to effectively treat VOCs from the air stripper offgas, feasibility studies for future treatment capacity at McClellan consider catalytic oxidation and vapor-phase granular activated carbon as additional options for handling air stripper offgas. Vapor-phase granular activated carbon is considered to generate less community acceptance problems and would reduce permitting complexity.

• The use of activated charcoal is cost effective for treatment of low water flow rates in the range of 2 to 10 GPM which generally corresponds to a carbon replacement occurring every three years. For relatively high flow rates, such as 200 GPM, and VOC contamination in excess of 10 ppm, charcoal alone is not cost effective due to the high frequency of carbon replacement.

• Ongoing feasibility studies at McClellan have identified air stripping and liquid granular activated carbon as the preferred groundwater treatment technologies for the east side of the base. These would be implemented along with demonstration and evaluation of innovate technologies primarily targeting hot spots.

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental
Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

for:

US Army Corps of Engineers
Omaha District

This analysis was funded by:

U.S. Air Force
Headquarters USAF/CEVR

CERTIFICATION

This analysis was prepared in cooperation with and was reviewed by McClellan personnel.
Critical assistance was provided by Badrul Hoda and Alec Elgal.

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 1, 4, 5, 6 and 7
Treatment System:	Source #s 1, 3, 4, 5, 6, 7 and 8
Performance:	Source #s 1, 2, 3, 4, 6 and 7
Cost:	Source #s 1 and 7
Regulatory/Institutional Issues:	Source #s 4 and 8
Schedule:	Source #s 1, 3, 4, 5, 6 and 7
Lessons Learned:	Source #s 2, 4 and personal communications with Alec Elgal, McClellan AFB (916) 643-0827

Chronological List of Sources and Additional References

1. *Data Package provided by Alec Elgal, Environmental Restoration Division, Environmental Management Directorate, McClellan Air Force Base,* February - April, 1994.

2. Personal Communications with Alec Elgal, Environmental Restoration Division, Environmental Management Directorate, McClellan Air Force Base, May-June, 1994.

3. *GWTP Weekly Reports,* prepared by Metcalf and Eddy Services for McClellan Air Force Base, through 10 January 1994.

4. Draft Copy, *Groundwater Operable Unit Remedial Investigation/Feasibility Study Report,* prepared by CH2M Hill for McClellan Air Force Base, November 1993.

5. *Basewide Groundwater Operable Unit, Groundwater Well Specific Data Report,* prepared by CH2M Hill for McClellan Air Force Base, 1993.

6. *Preliminary Groundwater Operable Unit Remedial Investigation (PGOURI),* prepared by Radian Corporation for McClellan Air Force Base, September 1992.

7. *Operable Unit B, Engineering Evaluation/Cost Analysis,* prepared by Radian Corporation for McClellan Air Force Base, October 1990.

8. *Operation and Maintenance Manual, McClellan Air Force Base Groundwater Treatment Facility,* prepared by Metcalf and Eddy for McClellan Air Force Base, Undated.

Pump & Treat of Contaminated Groundwater at Twin Cities Army Ammunition Plant, New Brighton, Minnesota (Interim Report)

Pump & Treat of Contaminated Groundwater at Twin Cities Army Ammunition Plant, New Brighton, Minnesota

Site Name:
Twin Cities Army Ammunition Plant (TCAAP)

Location:
New Brighton, Minnesota

Contaminants:
Chlorinated Aliphatics
- Contaminants of greatest concern in the groundwater are: 1,1-DCE, 1,1-DCA, 1,2-DCE, chloroform, 1,1,1-TCA, TCE, and PCE
- TCE is the most prevalent VOC on site, with concentrations greater than 10,000 ppb in groundwater

Period of Operation:
Status: Ongoing
Report covers - 10/87 to 9/92

Cleanup Type:
Full-scale cleanup (interim results)

Vendor:
Not Available

SIC Code:
9711 (National Security)

Technology:
Groundwater Extraction followed by Air Stripping
- 12 boundary recovery wells and 5 source area recovery wells
- Air stripping plant designed to treat 2,900 gal/min; 4 towers - 2 @ 7 feet diameter and 2 @ 8 feet diameter; all 36 feet tall with propylene packing
- Treated water discharged to a sand and gravel pit, or, alternately to an elevated tank
- Designed for an operating life of 30 years

Cleanup Authority:
CERCLA
- ROD Date: 10/88

Point of Contact:
Remedial Project Manager
Twin Cities Army Ammunition Plant
New Brighton, MN

Waste Source:
Other: Variety of Waste Disposal Practices, including Discharges to Sewer, Dumping, and Burning

Purpose/Significance of Application:
Pump and treat of large-volume of groundwater contaminated with VOCs.

Type/Quantity of Media Treated:
Groundwater
- Over 1.4 billion gallons of water pumped from 10/91 to 9/92
- Complex hydrogeology and heterogeneities in a multilayer aquifer system
- Fractured bedrock and discontinuous sand, clay, and till layers
- Hydraulic conductivity 0.001 to 137 ft/day; transmissivity 3,160 to 28,724 ft^2/day

Regulatory Requirements/Cleanup Goals:
- Several RODs apply to overall TCAAP remedial program, including a ROD for groundwater remediation
- Target cleanup criteria focus on residual levels of contamination in groundwater and containment of existing plume
- Target cleanup levels in groundwater include: TCE - 5 ppb; PCE - 6.9 ppb; 1,2-DCE - 70 ppb; and 1,1,1-TCA - 200 ppb

Pump & Treat of Contaminated Groundwater at Twin Cities Army Ammunition Plant, New Brighton, Minnesota (Continued)

Results:
- Boundary Groundwater Recovery System (BGRS) recovered an average of 23 pounds of VOCs per day
- TCAAP Groundwater Recovery System (TGRS) recovered 19,510 pounds of VOCs in one year of operation
- Historical total of 92,700 pounds of VOCs recovered in 6 years of operation (BGRS and TGRS)
- Plume containment successful at site
- VOC plumes changed little after several years of treatment; estimate of remediation time increased to achieve a concentration of 17 ppb TCE in 50 to 70 years

Cost Factors:
- Capital costs - $8,034,454 (including construction of treatment plant, wells, force main and pump houses, startup, engineering, and project management)
- Annual operating costs - $588,599 (including power, labor, maintenance, laboratory charges, and replacement of tower packing)
- Total Life Cycle Costing estimated as $0.30 per 1,000 gallons of water treated
- Total cost of operation and maintenance calculated as $0.12 per 1,000 gallons of water treated

Description:
The Twin Cities Army Ammunition Plant, established in 1941, has been used for the production and storage of munitions. The site includes 7 major production buildings and over 300 auxiliary buildings. A series of hydrogeological investigations beginning in 1981 revealed elevated levels of VOCs in groundwater; 14 separate source areas have been identified at the site. Trichloroethene (TCE) has been measured at concentrations over 10,000 ppb in the groundwater. Target groundwater cleanup levels were established for four constituents - TCE, PCE, 1,2-DCE, and 1,1,1-TCA.

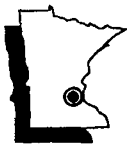
Groundwater extraction followed by air stripping has been used at this site since October 1987 to treat contaminated groundwater. The groundwater extraction system includes 12 boundary recovery wells and 5 source area recovery wells. Extracted groundwater is treated using four 36-feet tall air stripping towers. An estimated 92,700 pounds of VOCs have been recovered in 6 years of system operation. Although plume containment has been successful at the site, the plumes have changed little after several years of treatment.

An estimate of the time required for remediation has been revised from 30 years to 50 to 70 years, based on a review of data collected to date. Capital costs for this application were $8,034,454, and annual operating costs are $588,599.

TECHNOLOGY APPLICATION ANALYSIS

SITE

Twin Cities Army Ammunition Plant (TCAAP)
A CERCLA Site
New Brighton, Minnesota



TECHNOLOGY APPLICATION

This analysis covers an effort to **pump and treat groundwater** contaminated with volatile organic compounds (**VOCs**) by above ground **air stripping.** The treatment began in October 1987 and is currently ongoing. This analysis covers performance through September 1992.

SITE CHARACTERISTICS

Site History/Release Characteristics

- TCAAP is an approximately 4 square mile facility established in 1941 which primarily produced and stored munitions during the periods of 1941 to 1957 and 1966 to 1976. The site includes 7 major production buildings and over 300 auxiliary buildings. Most of the site is now in caretaker status, however, current lessees manufacture ammunition and other products.
- A series of hydrogeological investigations which began in 1981 revealed elevated levels of VOCs in groundwater. Fourteen separate source areas have been the focus of detailed site characterization and various remediation efforts.
- Contamination resulted from a variety of past waste disposal practices such as sewer disposal, dumping and burning which released process wastes, oil and grease, heavy metals and solvents to the environment.
- In October 1987 a Boundary Groundwater Recovery System (BGRS) started operation. An expanded system, the TCAAP Groundwater Recovery System (TGRS), began operation in January 1989. Additional smaller scale groundwater remediation efforts were implemented at the plant. Remedial actions were also conducted outside of the plant boundaries. This analysis will focus upon the performance of the BGRS and TGRS up through September 1992.

Contaminants of Concern

Contaminants of greatest concern in the groundwater are:

1,1-dichloroethylene
1,1-dichloroethane
cis-1,2-dichloroethylene (1,2-DCE)
chloroform
1,1,1-trichloroethane (1,1,1-TCE)
trichloroethylene (TRCLE)
tetrachloroethylene (TCLEE)

TRCLE, the most prevalent VOC on site, is the target compound used to measure system performance.

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Property at STP*	Units	TRCLE	TCLEE	1,2DCE	1,1,1-TCE
Empirical Formula	-	$ClCH{=}CCl_2$	$Cl_2C{=}CCl_2$	$CHCl{=}CHCl$	CH_3CCl_3
Density	g/cm^3	1.46	1.62	-	1.31
Vapor Pressure	mmHg	73	19	208	124
Henry's Law Constant	$atm{*}m^3/mole$	9.9E-3	2.9E-3	-	1.6E-2
Water Solubility	mg/L	1000-1470	150-485	3500	300-1334
Octanol-Water Partition Coefficient; K_{ow}	-	195	126	5	148
Organic Carbon Partition Coefficient; K_{oc}	-	66	209	-	105

**STP = Standard Temperature and Pressure; 1 atm, 25 °C*

Nature & Extent of Contamination

- Characterization of the nature and extent of contamination at TCAAP slowly evolved over several years of monitoring and treatment. In the mid 1980s it was known that a plume beneath the site had TRCLE concentrations as high as 3600 ppb (later analyses revealed levels over 10,000 ppb) as well as 1,2-DCE and 1,1,1-TCE levels of 160 and 950 ppb respectively. After installation of the BGRS, TGRS and associated monitoring wells more detailed plume delineation became possible.
- A plume extends over six miles downgradient (southwest) of the site; no contamination has been detected immediately upgradient of the site.
- Contaminants have been found to be fairly mobile in most geologic strata.

Contaminant Locations and Geologic Profiles

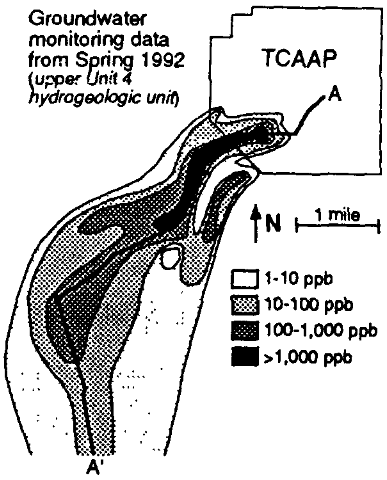
Remedial investigation field activities at the site have included:

- soil gas surveys
- surface soil sampling
- soil trenching and sampling
- soil boring installation and sampling
- groundwater well installation and sampling
- geophysical investigations (electromagnetic induction and ground penetrating radar)

Data from hundreds of soil borings and groundwater monitoring wells has allowed the development of numerous two-dimensional contour diagrams illustrating the upper and lower surface areas, groundwater elevations, and contaminant concentration profiles for various geologic units. Portions of some of these diagrams have been included here to provide a general conceptual understanding of site conditions.

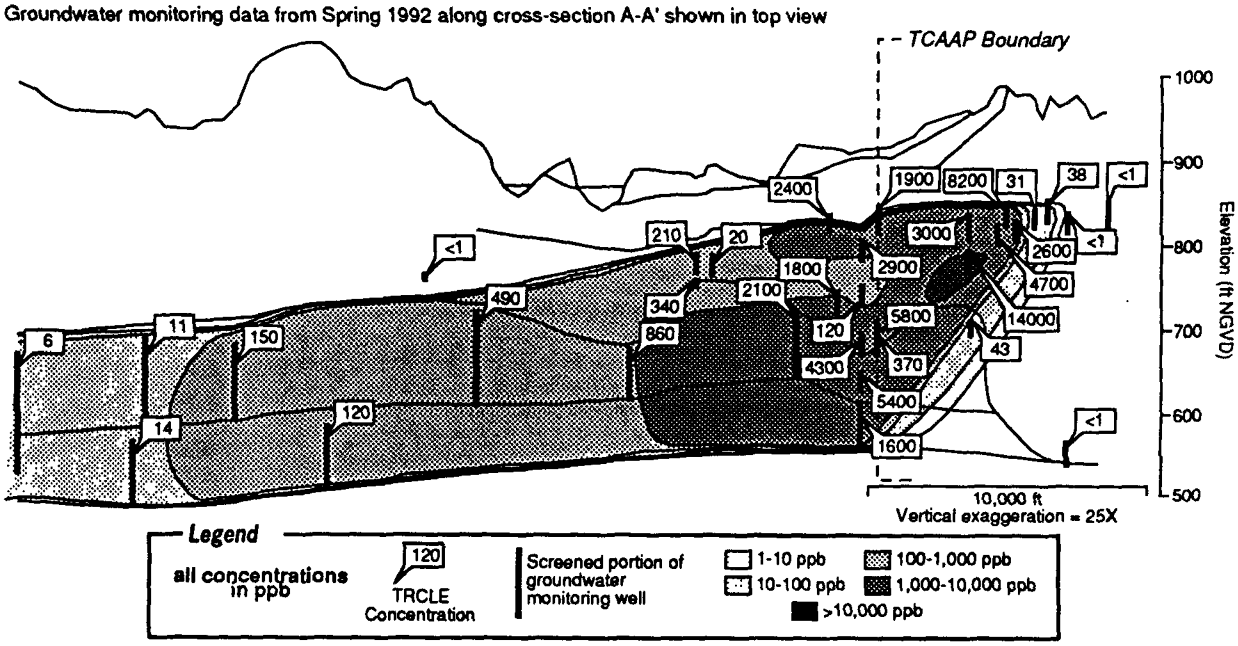
Recent (1992) data is used in these diagrams. Earlier plume delineation efforts were based upon less complete data sets. It is currently assumed that the plume outline has not changed significantly over the past several years.

TRCLE Plume (Unit 4 Top View)



TRCLE Plume (Side View)

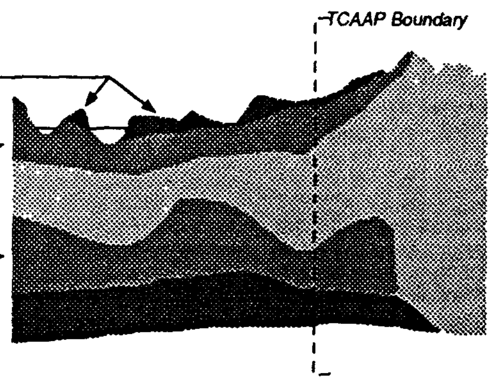
Groundwater monitoring data from Spring 1992 along cross-section A-A' shown in top view



Hydrogeologic Units

Four distinct hydrogeologic units have been identified beneath TCAAP and the surrounding regions:

Unit 1	New Brighton & Fridley Formations	Discontinuous recent alluvium and lacustrine deposits; discontinuous local water table aquifer; 0-50 ft thick
Unit 2	Twin Cities Formation	Discontinuous glacial till; acts as aquitard with some water bearing sand and gravel lenses; 0-150 ft thick
Unit 3	Hillside Sand	Overlain by Arsenal sand which forms kame in center of TCAAP; aquifer arbitrarily subdivided into upper middle and lower parts for monitoring; 25-450 ft thick
Unit 4	Prairie du Chien & Jordan Sandstone	Dolomite bedrock aquifer; 0-250 ft thick Sandstone bedrock aquifer; 0-100 ft thick



Site Conditions

• Surrounding region characterized by a continental climate with average yearly temperature of 44°F, rainfall of 25 inches, and snowfall of 40 inches.

• Topography at TCAAP ranges from 880 ft MSL at Rice Creek on the western edge to 1,000 ft MSL at the kame in the center of the site.

• Groundwater flow is generally to the west and southwest.

• The site possesses a complex hydrogeology arising from heterogeneities in the multilayer aquifer system, fractured bedrock, and discontinuous sand, clay and till layers.

Key Aquifer Characteristics

Aquifer parameters along the southwest TCAAP boundary have been estimated as:

Unit		Approximate Thickness [ft]	Hydraulic Conductivity [ft/day]	Transmissivity [ft^2/day]	Flow Direction
Unit 1	New Brighton and Fridley Formations	10	0.007-22	-	Recent alluvium. Reflects surface topography
Unit 2	Twin Cities Formation	63	0.001-0.01	-	Low conductivity aquitard; groundwater moves slowly downward to Unit 3
Unit 3	Hillside Sand	156	137	21,424	Generally horizontal and directed southwest and west; vertical gradient is downward and is <0.005
Unit 4	Prairie du Chien	37	85	3,160	Generally horizontal and directed southwest and west
Unit 4	Jordan Sandstone	90	46	4,140	Generally horizontal and directed southwest and west
Bulk Flow for Units 3 and 4		283	-	28,724	

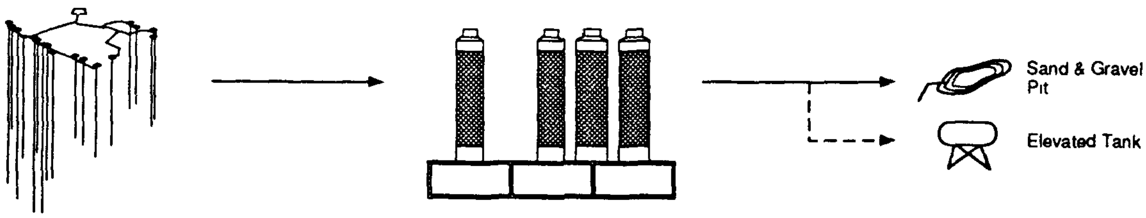
• A wide range of values has been used to describe regional aquifer characteristics. Uncertainties stem from difficulties in aquifer testing and interpretation methods applied to the hydrogeological complexities noted above under Site Conditions.

• Groundwater along the southwest TCAAP boundary is unconfined but becomes confined to the west and north. The confining boundary may change throughout the year due to seasonal groundwater table fluctuations.

TREATMENT SYSTEM

Overall Process Schematic

Extraction Well Network | **Treatment Plant** | **Forcemain & Discharge**

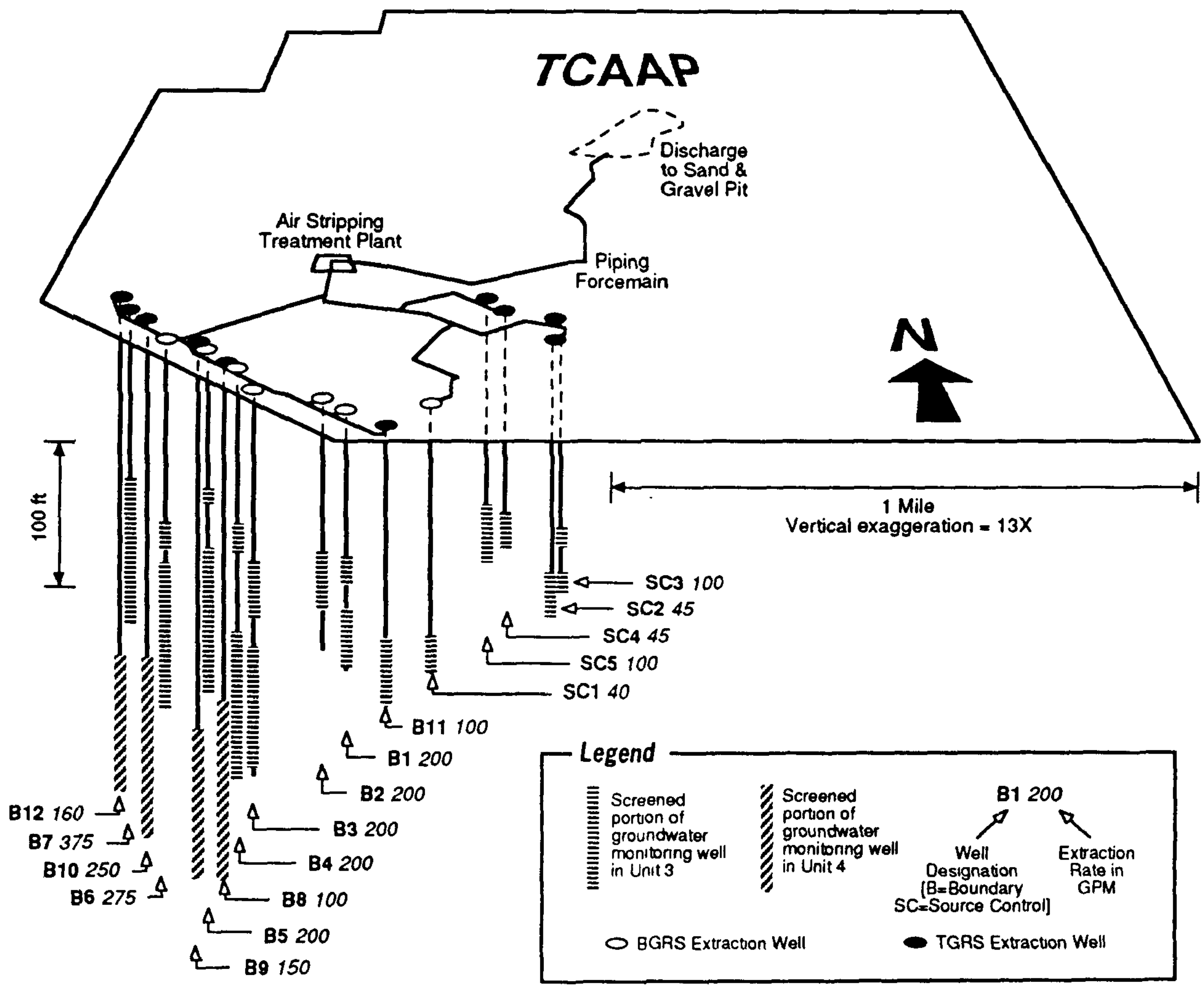


12 Boundary recovery wells and 5 source area recovery wells installed in two stages (first BGRS, then TGRS) [detailed below]

Air stripping plant treating 2900 GPM [detailed on next page]

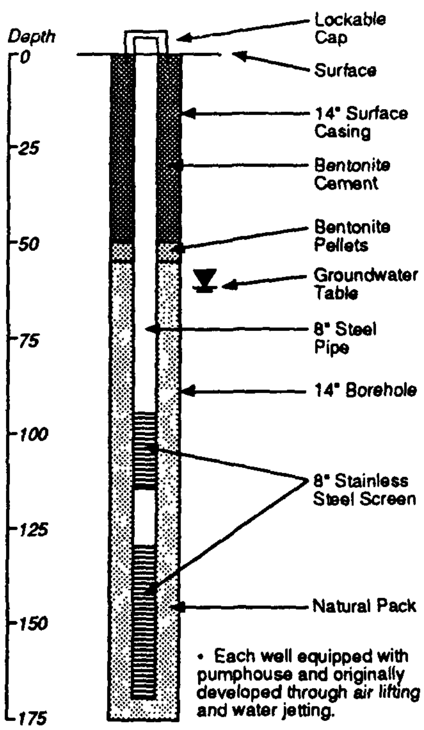
16" cement lined 150 psi pressure tested ductile iron pipe buried 7-10 ft below grade. Primary discharge point is a sand and gravel pit having extensive erosion protection. Alternate discharge to an elevated tank.

Extraction Well Network



Extraction Well Close-Up

Typical Unit 3 Extraction Well
(Well Shown is B1)



• Each well equipped with pumphouse and originally developed through air lifting and water jetting.

Key Design Criteria

- Operating life of 30 years (estimated remediation time).
- Handle maximum flow rates throughout system.
- Discharge to multiple points.
- Handle changes in flow rates.
- Operate with portions of system shut down.
- Minimal operating labor requirements.

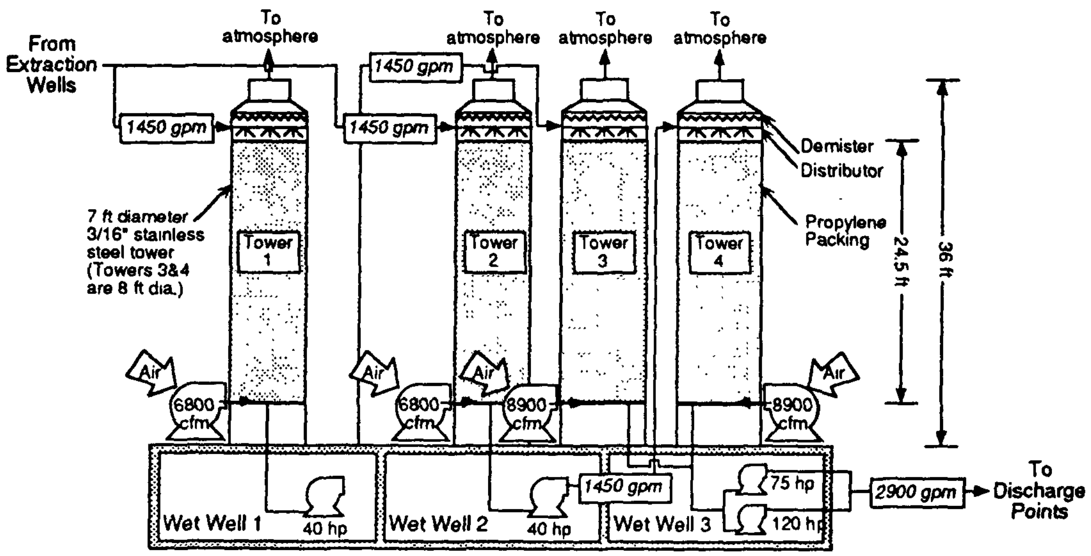
Key Monitored Operating Parameters

- Water flows
- Air flows
- Pump discharge pressures
- Automated processes

(to assess system operation)

- Groundwater levels
  (to assess zone of capture)
- Contaminant concentrations in treatment plant influent & effluent
  (to assess treatment effectiveness)
- Contaminant concentrations in groundwater
  (to assess achievement of remediation goals)

Air Stripper System Schematic



- Tower 4 was added for the TGRS arrangement. Previously, the BGRS system split 1200 gpm between Towers 1 and 2 with discharge from both going to Tower 3.
- Air compressor ratings represent minimum operating levels.
- Drawing not to scale.

PERFORMANCE

Performance Objectives

- Achieve cleanup goals including TRCLE concentrations of 5 ppb in groundwater (other criteria detailed within Regulatory/Institutional section).
- Prevent migration of contaminants off the TCAAP site.
- Design and operate treatment system such that its zone of capture contains the plume within the TCAAP boundary.

Treatment Plan

A phased approach was utilized to implement an overall TCAAP groundwater remediation program:

- Installation of BGRS
- Execution of a Performance Assessment Review (PAR) evaluating the first 90 days of BGRS operation.
- Recommendations from the PAR used to develop criteria for the TGRS.
- Installation of the TGRS.
- Further modifications to the system identified through yearly monitoring and performance assessment reports.

BGRS Startup
↓
90-Day Review
1-Year Review
↓
TGRS Startup
↓
Annual Reviews & System Modifications

Initial Process Optimization Efforts

BRGS Performance Assessment

Conclusions drawn after 90 days of BGRS operation and confirmed by 1 year of operating experience included:

- A substantial portion of Unit 3 & 4 groundwater and VOC plumes were captured based upon observed drawdowns.
- The treatment system processed an average of 23 lbs of VOCs/day (range of 17 to 29 lbs/day).
- VOC plumes showed little variation during treatment.
- Treated effluent satisfied contaminant specific requirements established in the Record of Decision (ROD) for interim measures.
- Air emissions met ROD requirements and were not detected upwind or downwind of the BGRS.
- The TGRS expansion should include four Unit 4 and two Unit 3 boundary extraction wells and four Unit 3 source control extraction wells and corresponding increases in flow handling and treatment facility capacities.

TGRS Performance Assessment

Conclusions drawn after 1 year of TGRS operation included:

- Hydraulic capture extended beyond the 5 ppb TRCLE contour at the TCAAP boundary in both Units 3 & 4.
- The TGRS extracted and treated 19,510 lbs of VOCs.
- VOC plumes showed little variation during treatment.
- Treated effluent satisfied contaminant specific requirements established in the ROD for interim measures.

Operational Performance

Volume of Water Pumped

- From Oct 1991 through Sept 1992 over 1.4 billion gallons of water were pumped from the 17 different extraction wells; monthly flow rates ranged from 112 to 123 million gallons.
- During this period 112% more water was pumped than was previously determined to be necessary to maintain a capture zone encompassing the VOC plume.

System Downtime

- The TGRS was operational 98% of the year ending Sept '92; this performance represented a slight improvement over '90 and '91 and a significant improvement over '89.
- A preventive maintenance program was instrumental in reducing system downtime.

<u>*Causes of downtime 10/91 to 9/92:*</u>

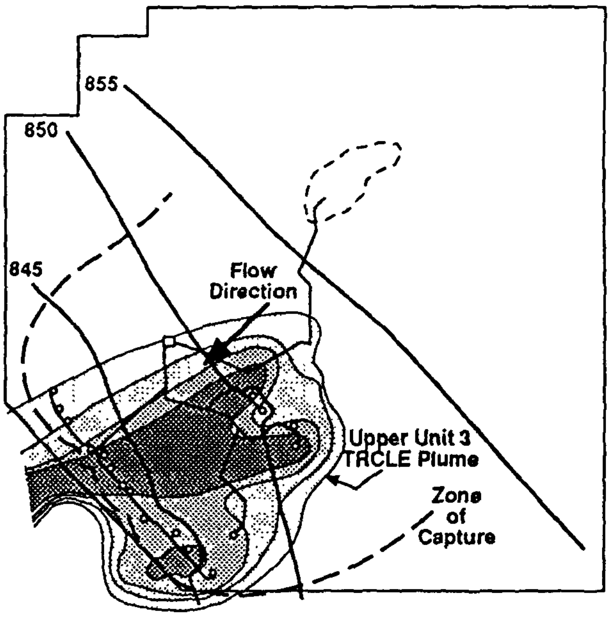
Repair to pumphouse	*1 .0 day*
Repair to treatment plant	*0.9*
Preventive maintenance	*0.1*
TCAAP power system failures	*4.2*
Total	***6.2 days***

Hydrodynamic Performance

- The zone of capture created by the TGRS extends beyond the 5 ppb TRCLE contour along the entire southwest TCAAP boundary. There is some ongoing debate among parties at TCAAP concerning the extent to which any part of the onsite contaminant plume may be breaking through the system of boundary extraction wells.
- The horizontal extent of capture is nearly identical throughout Units 3 & 4.
- Groundwater contours were manually constructed due to the complexities of the flow field and were based upon elevation measurements, pumping test analyses, drawdown analyses and vertical gradient analyses.

Legend

- o Extraction well
- 1-10 ppb
- 10-100 ppb
- 100-1,000 ppb
- >1,000 ppb
- 850 Groundwater elevation contour line



Treatment Performance

Effects on Plume

- VOC levels appear to have been reduced near source areas. Interim measures on soil may be the cause.
- Overall, VOC plumes have changed little. The plume configurations identified in 1992 are similar to those identified earlier. Original estimates of a 30 year remediation time have been revised and project achievement of 17 ppm TERCLE concentrations in 50 to 70 years.

TRCLE vs Time at Influent

- The concentration of TRCLE in groundwater extracted from each well and sent as *influent* to the air stripping plant:

has **decreased** over time for wells	B1, B2, B7, B10, B12, SC1, SC2 and SC3
has **increased** over time for wells	B5, SC4 and SC5
has shown no clear trend for wells	B3, B4, B6, B8, B9 and B11

- The trends may indicate plume redistribution and may also represent a decline in plume strength.
- There has been no clear reduction in overall contaminant concentrations sent to the treatment plant.

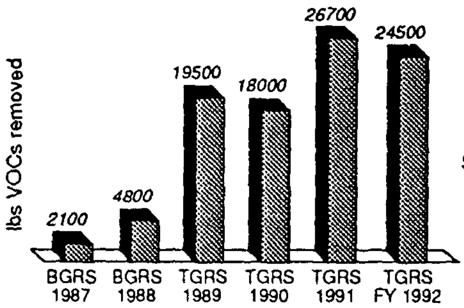
Influent vs Effluent

- Average TRCLE removal efficiency of 99.9%
- All VOCs, priority pollutants and metals treated below ROD discharge criteria.

Compound	Influent Lo	Influent Ave	Influent Hi	Effluent Lo	Effluent Ave	Effluent Hi
TRCLE	1200	1637	1900	bd	0.62	1.3
TCLEE	bd	bd	3	bd	bd	bd
1,2-DCE	-	-	-	bd	bd	bd
1,1,1-TCE	210	407	560	bd	bd	bd

bd = below detection

Total Pounds VOCs Removed



Historical Total: *92,700 lbs*

- Wells located near the center of the plume (B1, B4, B5, B6, SC2 and SC5) accounted for 95% of VOC mass removed.
- The five source control wells (SC1-5) removed 41% of the VOCs while pumping only 12% of the groundwater.

COST

An economic evaluation of the TCAAP air stripping facility was performed in 1990. The evaluation focused on determining (1) total capital cost, (2) operating costs and (3) significant cost elements.

In addition, the installed cost of the TCAAP facility was compared to two other groundwater air stripping facilities using total life cycle costing (TLCC) analysis based upon treatment of 1,000 gallons of water over the life of each plant. The TCAAP facility compared favorably based on the TLCC approach, however, theTCAAP system handled flow rates one order of magnitude larger than the other facilities. ***The TLCC at TCAAP was estimated to be $0.30 per 1,000 gallons of water treated. The total cost of operation and maintenance was calculated to be $0.12 per 1,000 gallons.***

Other results of the evaluation are summarized below in 1990 dollars.

Capital Costs

Construction of Treatment Plant	$774,757
Construction of Wells (16 extraction, 48 monitoring and 17 return wells)	1,026,406
Construction of Forcemain & Pumphouses (17,800 ft buried pipe, 16 pumphouses)	2,386,712
Startup	358,220
Health & Safety (Medical monitoring of employees)	110,125
Engineering	1,575,710
Project Management	928,267
Overhead & Profit	874,257
Total	**$8,034,454**

Operating Costs

Power (@ $0.04/Kwhr)	$148,846
Operating Labor	219,502
Maintenance Labor & Parts	150,054
Laboratory Charges	25,175
Other O&M Charges	39,518
Replacement of Tower Packing ($20,865 occurring every 5 years, annualized at 10% interest)	5,504
Total Annual Operating Cost	**$588,599**

Cost Sensitivities

Significant cost elements were:

Capital

• Pumphouses (16)	$775,964
• Extraction, monitoring & return well drilling (81)	399,633
• Stripping towers	296,821
• Extraction, monitoring & return well casings (81)	241,095
• Wet wells at base of stripping towers (3)	142,740

Operating

• Operating Labor	$219,502
• Maintenance labor & parts	150,054
• Electricity	148,846

REGULATORY/INSTITUTIONAL ISSUES

• BGRS construction was completed in April 1987 but startup was delayed until October 1987 due to administrative delays in obtaining regulatory approval to operate.

• Extraction well B1 was relocated from the original design since access to private property adjacent to TCAAP was denied.

• Groundwater in the New Brighton/Arden Hills area near TCAAP has led to abandonment of some municipal water supplies and private wells and necessitated the provision of bottled water in some instances. Municipal wells near TCAAP have added granular activated carbon treatment to meet water supply and remediation objectives.

• It is likely that the contaminant plume emanating from TCAAP has mixed offsite with plumes from other sources complicating allocation of responsibility and coordination of remedial response plans. More evaluation is needed.

• Various responsible parties at TCAAP have hired different consultants to manage aspects of the remedial response. In some cases, parties and their consultants have disagreed in their interpretations of environmental conditions and the performace of treatment systems. Responsible parties are bound by past lawsuits by the City of New Brighton, the City of St. Anthony, and 96 other plaintiffs.

• Regulatory oversight requires reporting any shutdowns or operational problems over 24 hours in duration and rapid development of accompanying plans for correction.

Cleanup Criteria

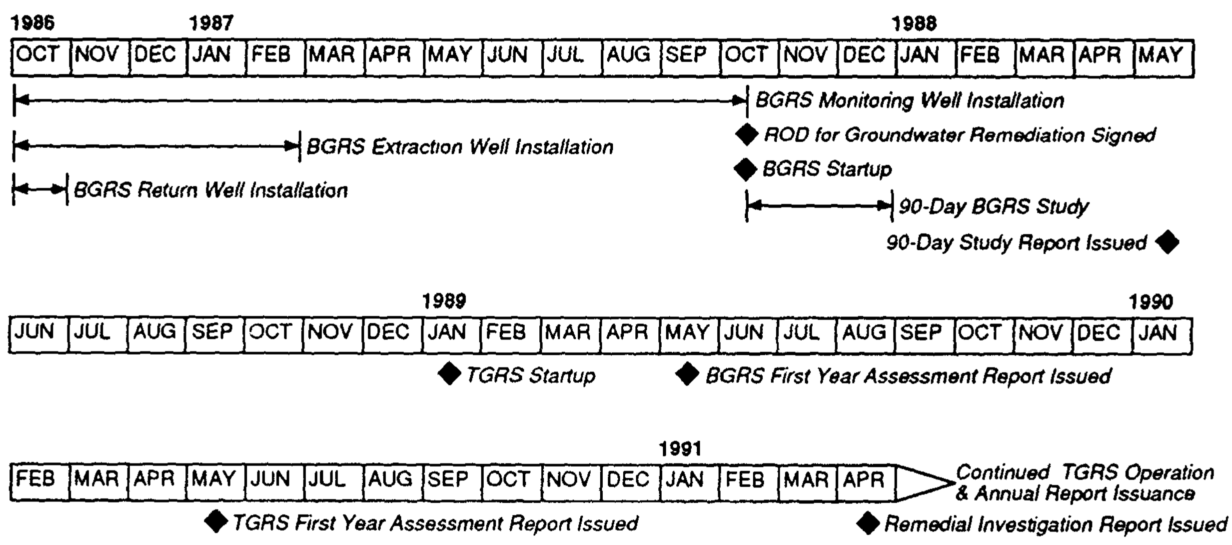
Several Records of Decision (RODs) apply to the overall TCAAP remedial program. Target cleanup criteria applicable to the BGRS and TGRS systems focus upon 1) residual levels of contamination in the groundwater and 2) containment of existing plumes.

Applicable target cleanup levels for major contaminants include:

Compound	*Criteria Level [ppb]*	*Compound*	*Criteria Level [ppb]*
TRCLE	5	1,2-DCE	70
TCLEE	6.9	1,1,1-TCE	200

SCHEDULE

BGRS & TGRS Installation History



LESSONS LEARNED

Key Operating Parameters

Implementation Considerations

• An understanding of the nature and extent of contamination at the site evolved over several years of monitoring and treatment. **Phased design** of the treatment system helped insure its proper sizing and effectiveness.

• Extensive **efforts to quantify and model aquifer properties** were of limited utility due to the presence of many hydrogeological complexities.

• A **preventive maintenance** program was instrumental in increasing the operational performance of the treatment facility.

Technology Limitations

• Original estimates of a 30 year **treatment period** have been extended. Minimum concentrations of target contaminants are projected to be achieved after 50-70 years of treatment. **Perpetual operation** of the system will be necessary to ensure continued containment of the VOC plume.

• As anticipated earlier, the technology is **not expected to achieve the 5 ppb target cleanup level** for TRCLE. It is projected that levels of 17 ppb may be achieved after 50 to 70 years of operation. **No alternative technology or system enhancements have been identified** to improve upon this performance to date.

• While plume containment appears to be successful, overall **VOC plumes appear to have changed little** after several years of treatment. Influent concentrations of contaminants to the the treatment plant have exhibited no clear downward trend. Extraction wells have experienced both increases and decreases in TRCLE concentrations from extracted groundwater. However, **only interim measures have been taken thus** far to clean up source areas. Permanent solutions are scheduled to be implemented in the 1995-1997 time frame.

Future Technology Selection Considerations

• The **zone of capture** created by the treatment system encompasses the entire contaminant plume of concern. There is some ongoing debate among parties at TCAAP concerning the extent to which any part of the onsite contaminant plume may be breaking through the system of boundary extraction wells.

• Operation of the treatment system in conjunction with **surface remediation of soils has been effective** at reducing VOC plume strengths near source areas.

• **Bioremediation is being considered** by regulators as a viable long-term solution to restore the aquifer to $\leq$ 5 ppb TRCLE. While selection of bioremediation is not currently anticipated, some technology must be implemented over the next 20-50 years to go below 17 ppb TRCLE.

• The **above ground air stripping system has been effective** at removing all VOCs, priority pollutants and metals to concentrations below discharge criteria. However, the air strippers simply transfer contaminants from the groundwater to the air. Granular activated carbon or other **emission control technology may be needed** in 1995 when new Clean Air Act requirements take effect.

• Groundwater treated by the air stripping systems is used as drinking water at TCAAP following post-treatment by granular activated carbon. **Identification of long-term drinking water used for treated effluent** will be part of future planning efforts.

• The system has been **effective at containing** further migration of the VOC plume off of the TCAAP site while **treatment of groundwater within subsurface aquifers to drinking water levels has not and is not expected to be achieved.**

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 1, 3 and 8
Treatment System:	Source #s 5 ,7 and 8
Performance:	Source #s 1, 4, 6 and 8
Cost:	Source # 2
Regulatory/Institutional Issues:	Source #s 1,2, 3, 4, 5, 6 and 8
Schedule:	Source #s 1,3,5 and 7
Lessons Learned:	Source #s 1,2, 3, 4, 6,8 and personal communications with Marty McCleary, Project Manager, TCAAP (612) 633-2301 ext. 651.

Chronological List of Sources and Additional References

1. *Fiscal Year 1992 Annual Monitoring Report; Installation Restoration Program Twin Cities Army Ammunition Plant*, prepared for Commander of Twin Cities Army Ammunition Plant and Commander of U.S. Army Toxic and Hazardous Materials Agency, prepared by Federal Cartridge Company, Wenck Associates, Inc., Alliant Techsystems, Inc., and Conestoga-Rovers & Associates, Ltd., July 1993.

2. *Technical and Economic Evaluation of Air Stripping for Volatile Organic Compound (VOC) Removal from Contaminated Groundwater at Selected Army Sites*, CETHA-TE-91023, prepared for U.S. Army Toxic and Hazardous Materials Agency, prepared by Tennessee Valley Authority National Fertilizer and Environmental Research Center, July 1991.

3. *Installation Restoration Program: Remedial Investigation Report for the Twin Cities Army Ammunition Plant*, (4 volumes), prepared for the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), prepared by the Environmental Assessment and Information Sciences Division, Argonne National Laboratory, April 1991.

4. *IRA-TGRS 1990 Annual Monitoring Report Installation Restoration Program Twin Cities Army Ammunition Plant*, (2 volumes), prepared for Commander of Twin Cities Army Ammunition Plant and Commander of U.S. Army Toxic and Hazardous Materials Agency, prepared by Alliant Techsystems, Inc., and Conestoga-Rovers & Associates, Ltd., February 1991.

5. *Final Engineering Report: Boundary Groundwater Recovery System (BGRS)*, prepared by Conestoga-Rovers & Associates, January 1991.

6. *IRA-TGRS 1989 Annual Monitoring Report Installation Restoration Program Twin Cities Army Ammunition Plant*, (2 volumes), prepared for Commander of Twin Cities Army Ammunition Plant and Commander of U.S. Army Toxic and Hazardous Materials Agency, prepared by Honeywell, Inc., and Conestoga-Rovers & Associates, Ltd., May 1990.

7. *TGRS Operations and Maintenance Manual; Installation Restoration Program Twin Cities Army Ammunition Plant*, (5 volumes), prepared for Commander of Twin Cities Army Ammunition Plant and Commander of U.S. Army Toxic and Hazardous Materials Agency, prepared by Honeywell, Inc., and Conestoga-Rovers & Associates, Ltd., October 1989.

8. *SMCTC-EV Review Comments on the Technology Application Analysis Draft Report*, prepared by U.S. Army Environmental Center, September 1993.

Pump and Treat of Contaminated Groundwater at U.S. Department of Energy, Kansas City Plant Kansas City, Missouri (Interim Report)

Case Study Abstract

Pump and Treat of Contaminated Groundwater at U.S. Department of Energy, Kansas City Plant Kansas City, Missouri

<table>
<tr><td>Site Name:
U.S. Department of Energy (DOE) Kansas City Plant</td><td rowspan="2">Contaminants:
Chlorinated Aliphatics; includes Tetrachloroethene (PCE), Trichloroethene (TCE), 1,2-Dichloroethenes (1,2-DCEs), and Vinyl Chloride
PCBs, Petroleum Hydrocarbons, and Metals
- TCE concentrations of > 10,000 μg/L in groundwater
- Presence of DNAPLs suspected</td><td>Period of Operation:
Status: Ongoing
Report covers - 5/88 to 2/94</td></tr>
<tr><td>Location:
Kansas City, Missouri</td><td>Cleanup Type:
Full-scale cleanup (interim results)</td></tr>
<tr><td>Vendor:
Allied Signal, Inc.</td><td rowspan="2">Technology:
Groundwater Extraction with Advanced Oxidation Processes (AOPs)
- 14 extraction wells and one trench; screened intervals of wells ranged from 27 feet to approximately 47 feet below ground surface; flow rates ranged from 0.9 to 5 gallons per minute (gpm) based on a design flow rate of 2 gpm
- Interceptor trench of 250 ft. in length; ranged in depth from about 22 ft. to 31 ft.
- Treatment system - acidification to solubilize inorganic metals, bag filtration, UV/peroxide oxidation, and neutralization
- Initial AOP - UV/Ozone/Peroxide system replaced in May 1993 with a high intensity UV/Peroxide system</td><td>Cleanup Authority:
RCRA Corrective Action and Other: Kansas City Water and Pollution Control Department</td></tr>
<tr><td>SIC Code:
9711 (National Security)
3724 (aircraft-engine manufacturing)</td><td>Point of Contact:
G.P. Keary
Environmental Restoration Program Manager
DOE Kansas City Plant
Kansas City, MO</td></tr>
<tr><td>Waste Source:
Manufacturing Process</td><td colspan="2">Type/Quantity of Media Treated:
Groundwater
- 11.2 million gallons treated (1993)
- Horizontal/Vertical distribution of VOCs in groundwater - up to 4,000 ft. horizontal and over 40 ft. vertical
- Alluvial deposits underlain by bedrock consisting of sandstone and shale
- Shale is relatively impermeable
- Porosity of aquifer is 20%
- Horizontal Hydraulic Conductivity of aquifer is 1.1 to 2.3 ft/day; sandstone is 0.04 to 0.005 ft/day; underlying shale is impermeable in water</td></tr>
<tr><td colspan="3">Purpose/Significance of Application:
Full scale remediation of groundwater contaminated with VOCs using advanced oxidation processes (UV/peroxide).</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
- Final cleanup goals for site have not been established at time of report; will be set subsequent to RFI/CMS activities
- Treated groundwater discharged to municipal sewer system must meet requirements of permit issued by the Kansas City Water and Pollution Control Department; for organics - total organic halogen 0.16 mg/L; metals - 0.69 to 100 mg/L</td></tr>
</table>

Pump and Treat of Contaminated Groundwater at U.S. Department of Energy, Kansas City Plant Kansas City, Missouri (Continued)

Results:
As of February 1994:
- Influent VOC concentrations to UV/Peroxide treatment system were 10.6 mg/L with an average influent concentration of 25 mg/L; effluent concentrations were 0.01 mg/L
- The UV/peroxide system destroyed > 99.95% VOCs
- PCBs were detected at levels up to 0.3 µg/L in influent to UV/peroxide unit; not detected in effluent
- VOC contaminant plume appears to be contained
- No significant change in VOC groundwater concentrations at this time

Cost Factors:
- Total Capital Costs: $1,383,400 (including equipment, site preparation, construction/engineering, startup)
- Annual Operating Costs: $355,200 (including maintenance, project management, laboratory analysis, supplies)
- An estimated total cost for completing the cleanup is not available at this time.

Description:
The U.S. Department of Energy (DOE) Kansas City Plant, constructed in 1942, has been used for aircraft engine manufacturing, production of nuclear weapons components, and defense-related research and manufacturing operations. During the 1980s, hydrogeologic investigations identified soil and groundwater contamination at the site which had resulted from releases from the research and manufacturing operations. The primary contaminants detected included chlorinated VOCs, aromatic VOCs, PCBs, and metals. DNAPLs are suspected in the groundwater, but have not been detected at this time. Final cleanup goals have not been established at this time. Treated water from the system is discharged to the municipal sanitary sewer system under the provisions of a Kansas City Water and Pollution Control Department wastewater discharge permit (2/88).

Operation of a groundwater pump and treat system, which includes an Advanced Oxidation Process (AOP), began in May 1988 under RCRA corrective action. The initial system included 14 extraction wells followed by a low intensity Ultraviolet (UV)/Ozone/Peroxide treatment system. This system was replaced in May 1993 by a high intensity UV/Peroxide system to provide additional 30 GPM treatment capacity for groundwater and to correct operational problems with the initial unit (equipment malfunctions and downtime). While the cleanup is ongoing at this time and final performance data are not yet available, interim results indicate that the extraction system appears to be containing the VOC contaminant plume. However, the concentrations of VOC in the groundwater have not changed significantly.

The total capital costs for this application were $1,383,400 and the annual operating costs were $355,200. With respect to the AOP, the replacement of the low intensity UV/ozone/peroxide system with the high intensity UV/peroxide system resulted in both increased treatment capacity and cost savings while meeting the discharge limits for the treated water. The high intensity UV/peroxide system eliminated the need for GAC polishing and treatment of air emissions and reduced operation and maintenance costs. Although more expensive than alternatives such as air stripping, AOP was selected because it destroys the contaminants rather than transferring contaminants to other media.

TECHNOLOGY APPLICATION ANALYSIS

SITE

U.S. Department of Energy
Kansas City Plant (KCP)
A RCRA Corrective Action Site
Kansas City, Missouri

TECHNOLOGY APPLICATION

This analysis covers an effort **to pump and treat groundwater** contaminated with volatile organic compounds **(VOCs)** by above ground **advanced oxidation processes (AOPs)**. The treatment began in May 1988 and is currently ongoing. This analysis covers performance through February 1994.

SITE CHARACTERISTICS

Site History/Release Characteristics

- The KCP is located within the Bannister Federal Complex approximately 13 miles south of downtown Kansas City, Missouri. The complex is bordered on the east by the Blue River and on the south by Indian Creek.
- Constructed in 1942 as an aircraft engine manufacturing facility, the KCP is part of the U.S. Department of Energy's (DOE) Albuquerque Operations Office. The Atomic Energy Commission, predecessor to the DOE, began production of components for nuclear weapons at the KCP in 1949. Subsequent defense related research and manufacturing operations resulted in the release of contaminants to the subsurface.
- A series of hydrogeologic investigations initiated in the early/mid 1980s revealed elevated contaminant concentrations (primarily chlorinated VOCs) in soil and groundwater.
- A groundwater pump and treat system, the subject of this report, started operation in May 1988. That system was designed as an interim remedial measure to prevent further migration of VOC-contaminated groundwater while additional RCRA Facility Investigation (RFI) and Corrective Measures Study (CMS) efforts to define final site remedial measures were being performed. A low intensity Ultraviolet (UV)/Ozone (O_3)/Hydrogen Peroxide (H_2O_2) treatment system operated until May 1993 when it was replaced by a high intensity UV/H_2O_2 system. The initial system was a demonstration of first-generation AOP technology; the replacement system is considered second-generation technology.

Contaminants of Concern

Contaminants identified as being of greatest concern in groundwater at the KCP are:

Tetrachloroethene	(PCE)
Trichloroethene	(TCE)
1,2-dichloroethenes	(1,2-DCEs)
Vinyl chloride	

Other contaminants detected in soil or groundwater include aromatic and halogenated VOCs, petroleum hydrocarbons, PCBs and selected metals.

Arsenic, present at concentrations higher than drinking water standards, was determined to be the result of natural geochemical processes.

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Properties*	Units	PCE	TCE	1,2-DCEs**	Vinyl Chloride
Density	-	1.62	1.46	1.25/1.27	0.91
Vapor Pressure	mm Hg	95.2	28.1	7	245
Henry's Law Constant	atm•m^3/mole	0.0259	0.0091	0.0066/ 0.0076	0.0144
Water Solubility	mg/l	150	1,100	2,250/3,3500	2,670
Octanol -Water Partition Coefficient; K_{ow}	-	398	240	3/5	24
Organic Carbon Partition Coefficient; K_{oc}	-	364	126	49/59	57

** Properties at 20 °C.* *** Data presented for both cis and trans-isomers.*

Nature & Extent of Contamination

- Characterization of the nature and extent of contamination at the KCP evolved over a number of years of investigation and interim remediation. Thirty-seven solid waste management units were found to have contributed to three primary areas of groundwater contamination known as: the TCE Still Area, the Underground Tank Farm Area, and the Northeast Area/Outfall 001 Area.
- Groundwater contamination is largely confined within the KCP limits. However, chlorinated VOCs have migrated with groundwater along a backfilled stream channel to the Blue River northeast of the KCP.
- The vertical distribution and concentrations of VOCs in soil and groundwater suggest the potential presence of dense non-aqueous phase liquid (DNAPL) in several areas which contribute to groundwater contamination.
- The presence of numerous subsurface utilities/utility trenches, including building footing tile drains, have a significant impact on contaminant migration at the KCP site. These utilities act as sources of recharge water, preferential migration pathways, and collectors for contaminated groundwater.

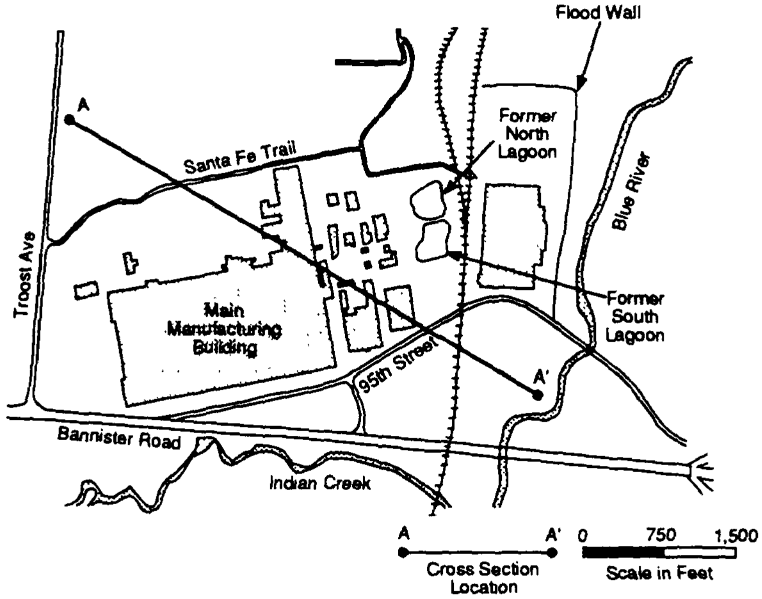
Contaminant Locations and Geologic Profiles

Remedial investigation field activities at the site have included:

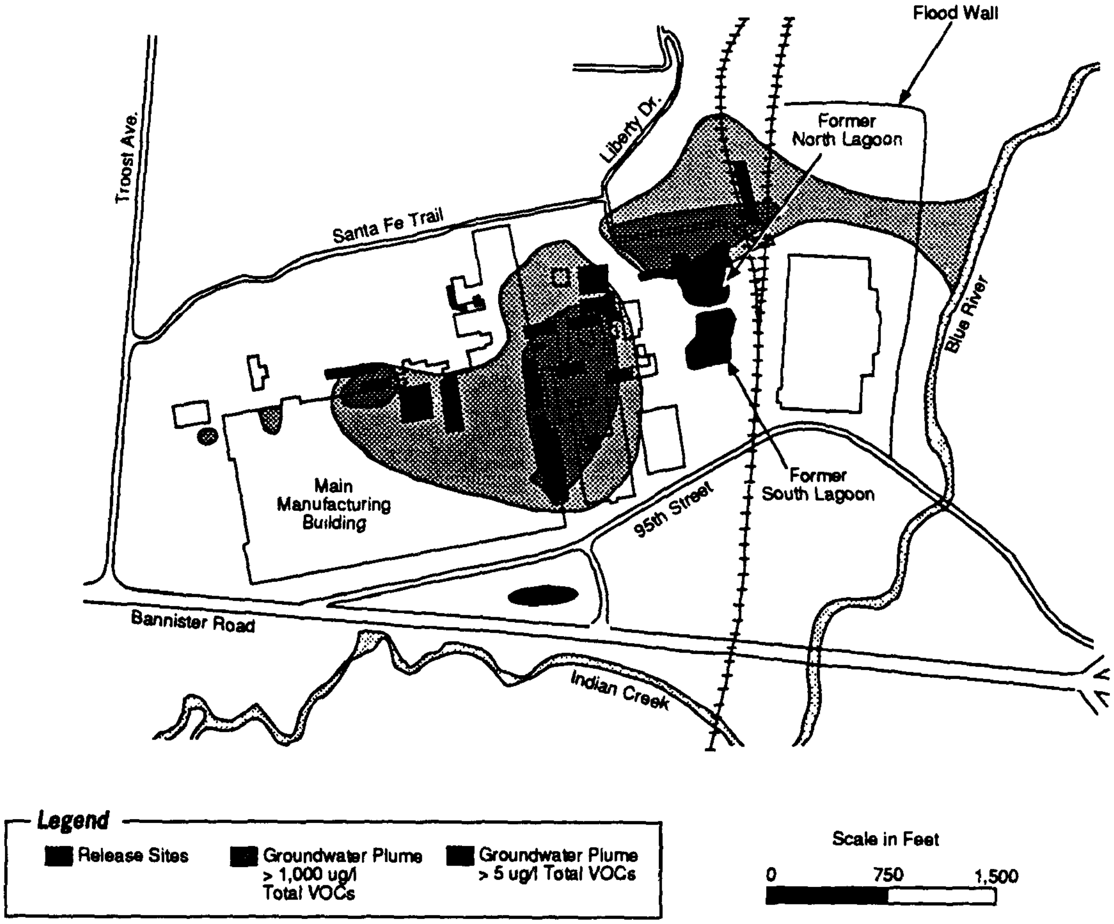
- Borings and subsurface soil sampling
- Monitoring well installation and groundwater sampling
- Groundwater elevation measurements
- Geophysical testing
- Water source/sink assessment
- Hydraulic tests
- Borehole packer testing
- Surface water sampling and elevation measurements
- Groundwater modeling

Data from ~200 soil borings and ~190 monitoring/extraction wells were used to develop an understanding of subsurface conditions, including contaminant migration. Selected data from site studies have been used in this report to depict site conditions.

Site Layout (Plan View)



Horizontal Distribution of VOCs in Groundwater - Generalized Representation (Plan View)



Contaminant Locations and Geologic Profiles (Continued)

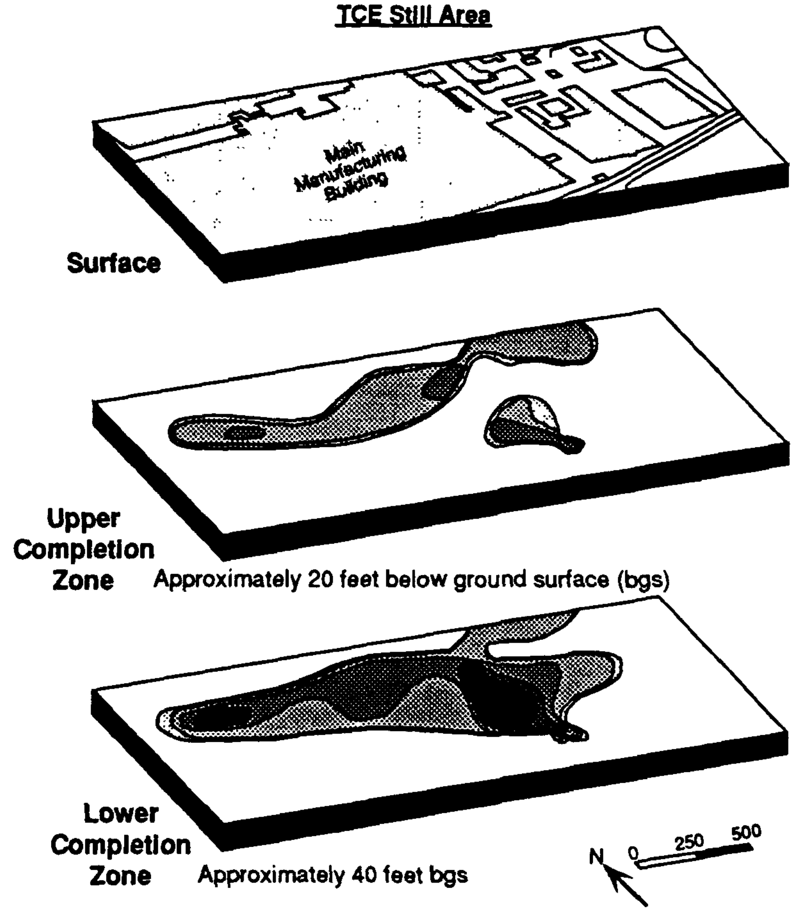
Vertical Distribution of VOCs in Groundwater

• In general, concentrations of prime contaminants of concern in groundwater increase with depth in overburden soils at the KCP site. Dense non-aqueous -phase liquid(s) (DNAPL) may be present in some areas. The figure below, illustrating TCE concentrations in groundwater at one of the 3 primary contamination areas (the TCE Still Area), is representative of the vertical distribution of chlorinated VOCs at the KCP site.

• Alluvial deposits at the KCP site are under lain by bedrock consisting of alternating layers of sandstone and shale. A thin layer of sandstone (< 10 feet thick) immediately beneath the alluvium pinches out beneath the site. Packer testing performed on the shale indicated it was relatively impermeable. No bedrock migration of VOCs has been observed.

• Because the bedrock surface dips in the opposite direction as alluvial groundwater flow, additional monitoring wells were completed within the shallow sandstone at the request of EPA to monitor for the potential migration of VOCs. No VOCs or dissolved-phase contamination have been detected in these wells. Additionally, contaminant transport modeling predicted that VOCs (if present) would migrate at an average rate of < 1 foot per year under worst-case conditions in the sandstone.

TCE Still Area

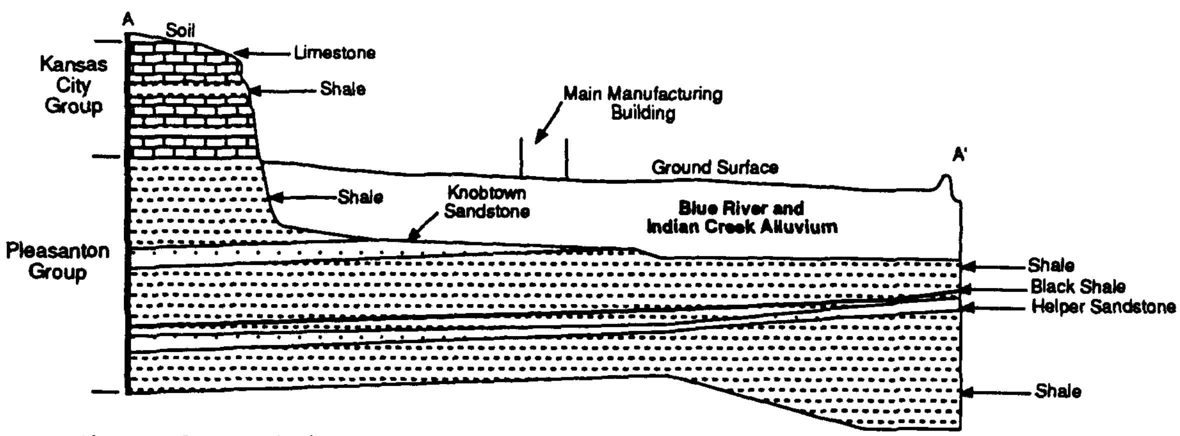


Legend

TCE Concentrations in Groundwater (July 1993)

- 0 to 10 ug/l
- 10 to 100 ug/l
- 100 to 1,000 ug/l
- 1,000 to 10,000 ug/l
- >10,000 ug/l

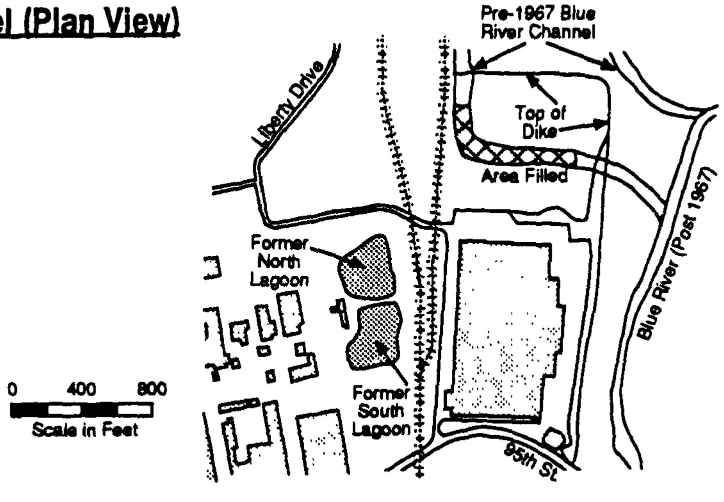
Schematic Cross-Section of Bedrock and Alluvium at KCP



Notes: Cross section is not to scale.
Cross section location shown on site map (page 2).

Location of Old Blue River Channel (Plan View)

The former Blue River channel, now filled, has a hydraulic conductivity an order of magnitude greater than the surrounding soil. This former river channel is serving as a preferential pathway for migration of contaminated groundwater from the Northeast Area/001 Outfall to the current location of the Blue River.



Groundwater Sinks and Sources

Several site structures (in addition to the extraction wells and interceptor trench) serve as sinks/collectors for groundwater on the KCP site and impact contaminant migration. Groundwater drains include: the 001 Outfall Interceptor system [~6,000 gallons per day (GPD)], which is a collection system to prevent groundwater infiltration into an NPDES storm sewer, a sump for the building southwest of the former South Lagoon, building footer drains, and possibly the plant sewer lines. Building drains control the surface of the water table in the vicinity of the Main Manufacturing Building.

In addition to recharge due to infiltrating precipitation, it is believed that leaking underground water and steam lines could be serving as a source of water to the subsurface. The KCP has initiated a study to quantify artificial sinks and sources of water in the subsurface at the KCP site.

Site Conditions

• The KCP is situated in the Blue River Valley about 800 feet above Mean Sea Level (MSL) and is in the 100-year flood plain of the both the Blue River and Indian Creek. However, a 500 year event floodwall protects the site.

• Approximately 46% of the site is covered by grass or gravel and is available for recharge. The site receives ~ 34 inches of precipitation per year.

• The topography of the complex is flat-lying except where it drops ~ 30 feet along the Blue River and Indian Creek and where it rises ~ 50 feet north of the KCP site.

• The Pennsylvanian bedrock (shales) in the vicinity of the KCP is noted for its uniformity. There are no structural features such as faults, that affect the KCP site. No fractures were observed in bedrock (shale) cores performed at the KCP site.

• The surface of the bedrock at the KCP site slopes to the east, reflecting surface topography. However, the slope or dip of individual layers (sandstones and shales) is to the west. Site lithologic logs indicate the presence of ~1 to 3 feet variation in the elevation of the bedrock surface.

• Groundwater flow at the KCP site is primarily to the east and discharges to the Blue River and Indian Creek. A portion of the KCP site groundwater flow is to the south.

Key Aquifer Properties

Aquifer parameters for the alluvial deposits at the KCP site have been estimated as:

Property	Units	Tank Farm	South Lagoon	Northeast Area
Porosity	%	20	20	20
Hydraulic Gradient	ft/ft	0.002	0.008	0.007 to 0.02
Horizontal Hydraulic Conductivity*	ft/day	2.3	1.1	1.5
Groundwater Velocity	ft/yr	8.4	16	19 to 55
Storage Coefficient**	-	0.002	0.0005	0.002

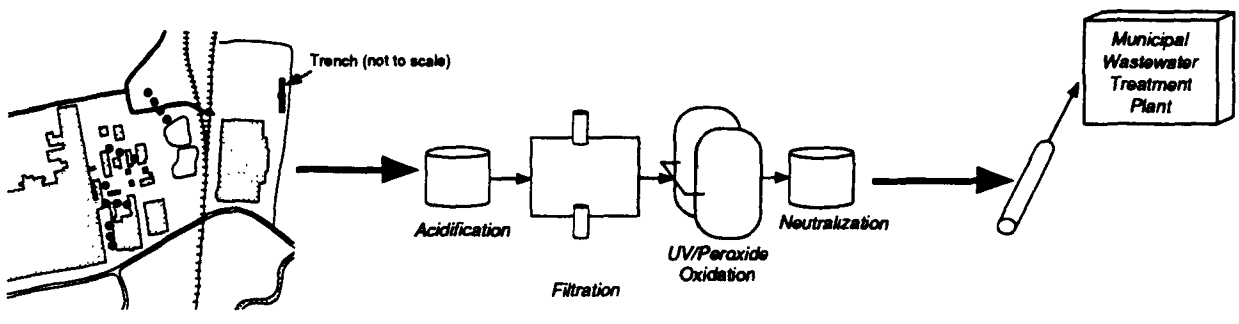
* Based on pumping test data. Conductivities calculated from bail and slug test data were ~ one order of magnitude lower.

** Low values are reflective of the fine-grained nature of the aquifer materials.

The horizontal hydraulic conductivity of the shallow (knobtown) sandstone is 0.04 to 0.005 ft/day. The underlying shale is impermeable to water.

REMEDIATION SYSTEM

Overall Process Schematic

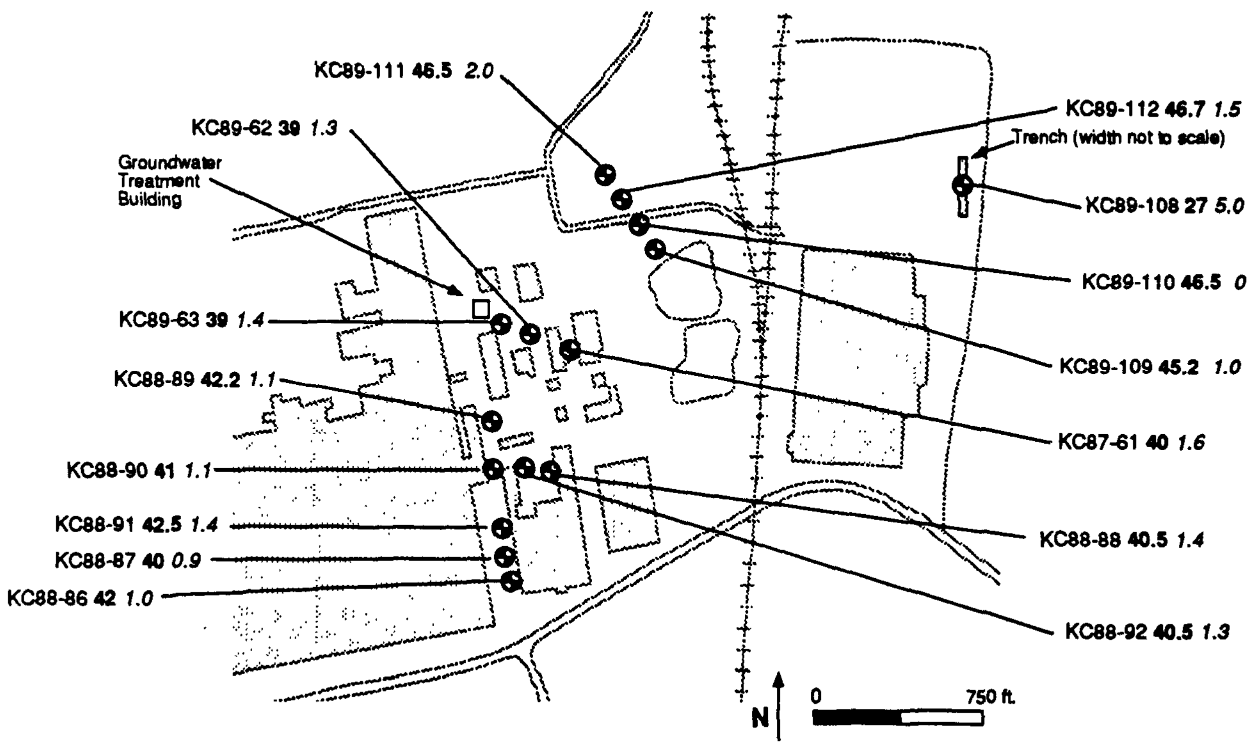


Fourteen extraction wells and one trench installed in three phases (1987, 1988, and 1989).

Acidification to solubilize inorganic metals, bag filtration, (UV/peroxide) oxidation of organic contaminants in one of two reactors, and subsequent neutralization.

Discharge treated water to municipal wastewater treatment plant.

Extraction Well Network



Legend

Extraction Well

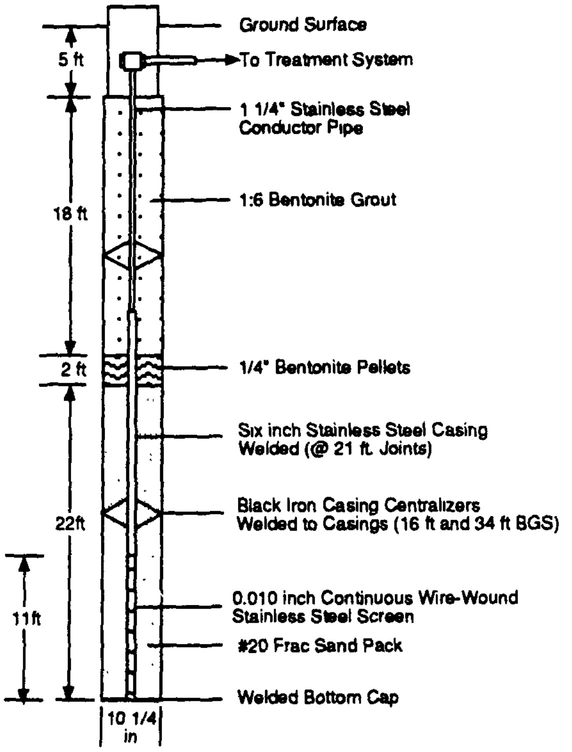
KC88-92 40.5 1.3

- Well Identification Number
- Bottom Depth of Screened Interval (Screened Lengths Vary from 10 to 11 feet)
- Flow Rate in Gallons per Minute (GPM)

The design flow for each of the wells was 2 gpm, however slight fluctuations occured.

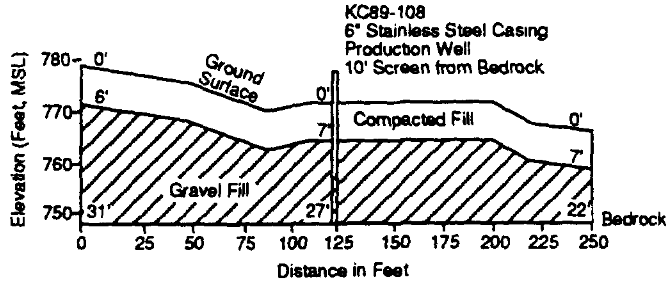
Extraction Well Detail

Typical extraction well (KC89-112)



NOTES: 1.) *Some extraction wells completed with subsurface vaults*
2.) *Submersible pumps with stainless steel impellers in each well*

Interceptor Trench Schematic



Key Design Criteria

- Hydraulic containment of VOC-contaminated groundwater
- Handle range of flow rates to allow for operational flexibility
- Destruction of organic contaminants in extracted groundwater rather than transfer to another media
- Redundant treatment capability to maintain hydraulic containment *in the event of unanticipated breakdown,* and to provide for treating increased flow rates during future-final site remediation

Key Monitored Operating Parameters

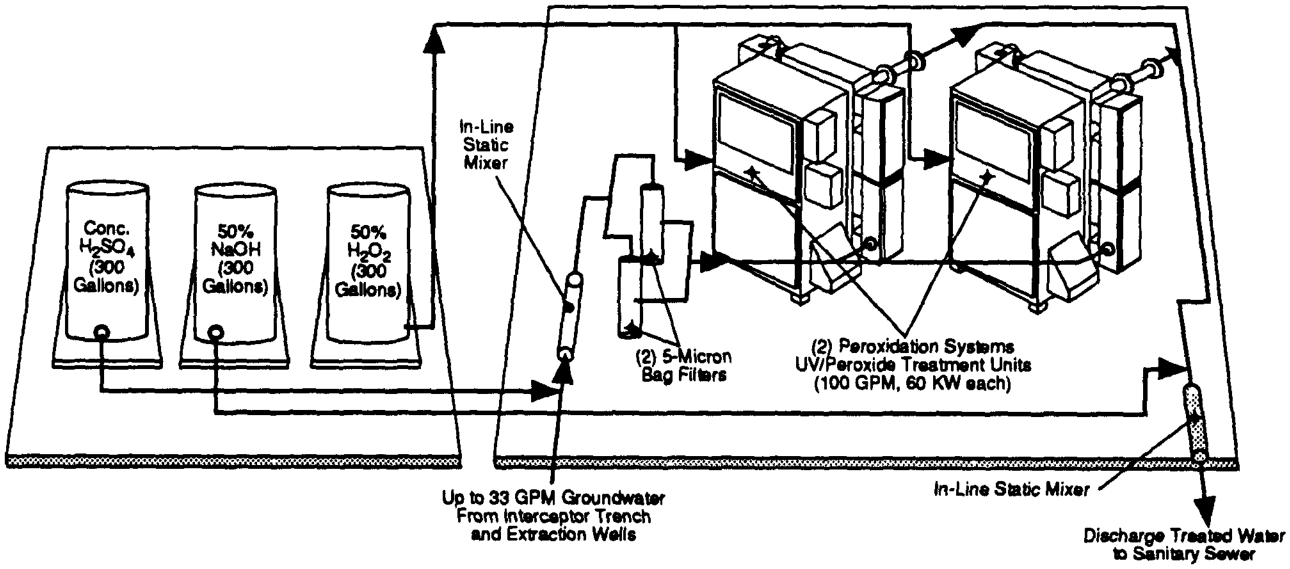
- *Groundwater elevations*
- Groundwater VOC concentrations

(to assess containment system performance)

- Water flow rates
- Temperature, pressure, and pH
- UV and H_2O_2 dosage
- Filter pressures
- Influent/effluent contaminant concentrations

(to assess treatment system operation and effectiveness)

Treatment System Schematic



PERFORMANCE

Performance Objectives

- Prevent further migration of VOC-contaminated groundwater from 3 areas of identified contamination
- Design and operate treatment system to decrease VOC concentrations in extracted groundwater to below sewer discharge limits

Remedial Action History/Plan

Remediation at the KCP site is being implemented in a phased manner. The following groundwater-related interim remedial actions have been performed to date:

1988 Initiated pumping of groundwater (6 GPM) from Underground Tank Farm Area and treatment with $UV/O_3/H_2O_2$ system as interim measure and to demonstrate treatment technology

↓

1990 Treatment of additional 14 GPM from TCE Still Area and 13 GPM from Northeast Area/001 Outfall using the same treatment system with additional Aqueous-Phase Granular Activated Carbon (GAC) polishing

↓

1993/1994 Second-generation UV/H_2O_2 *treatment system installed* to provide capacity for treating an additional 30 GPM (approximate) of groundwater from the 001 Outfall Area, and to provide additional operational and environmental benefits

Overall Performance Summary

Conclusions drawn after 5 (plus) years of operating the interim pump and treat system are summarized below:

- The extraction system appears to have been effective in substantially containing VOC-contaminated groundwater emanating from the KCP site. The KCP expects to begin extracting up to an additional 30 GPM of VOC-contaminated groundwater to prevent its infiltration into the 001 Outfall storm sewer line during 1994.
- The concentrations of VOCs in groundwater and the extent of contamination has not changed considerably in the TCE Still Area, Underground Tank Farm Area or the Northeast Area/001 Outfall since initiating the Interim Remedial Action.
- While the initial AOP treatment system met discharge limits, ozone leaks, the need to treat air emissions and significant downtime required for maintenance contributed to the decision to change to the high-intensity UV/H_2O_2 AOP. The new AOP system has also operated within discharge limits.

Operational Performance

Volume and Rate of Water Pumped/Treated

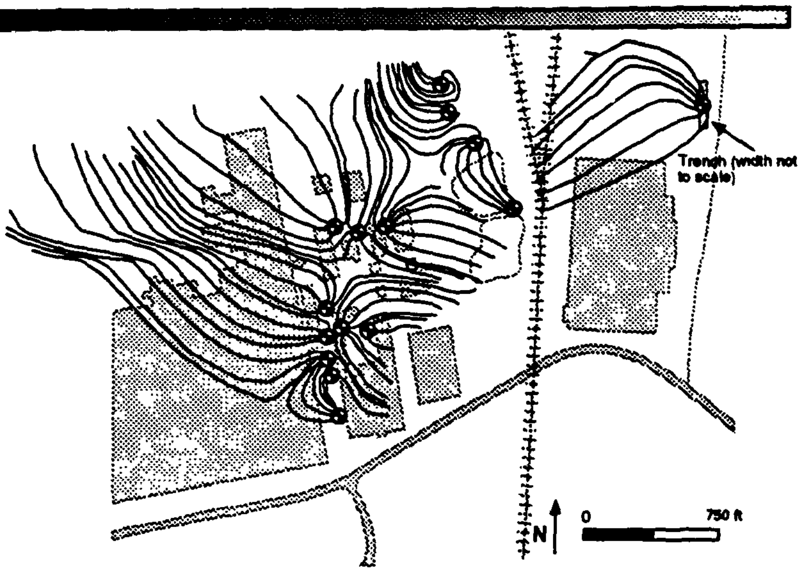
- During 1993, a total of approximately 11.2 million gallons of groundwater water was extracted and treated by the interim system. Of this total, ~2.2 million gallons was extracted from the Underground Tank Farm Area ~4.5 million gallons from the TCE Still Area and ~4.5 million gallons from the Northeast Area/001 Outfall.
- The average daily flow rate for the entire interim system in 1993 varied from a high of 32 GPM in January to < 2 GPM in July, during treatment unit replacement.

System Downtime

- Numerous equipment malfunctions and a significant amount of downtime occurred during the first 15 months (May 1988 - July 1989) of continuous operation of th $UV/O_3/H_2O_2$ system. The system operated > 65%of the time in 1988 except during *September* when it was shut down *for equipment modifications. The interim system operated* 61% *of the time in* 1989 *except* during June when it was down for servicing modifications by the manufacturer. Except during downtime periods for construction, equipment, modifications and frozen pipes, and the $UV/O_3/H_2O_2$ system operated > 90% of the time from 1990 until May 1993 when it was replaced by the high intensity UV/H_2O_2 system.
- The replacement UV/H_2O_2 system commenced continuous operation in August/September 1993. This treatment system has operated > 95% of the time. Much of the maintenance that required the prior treatment system to be shut down can now be performed while the replacement system remains operational.

Hydrodynamic Performance

• A modeling evaluation performed in May 1992 concluded that the extraction system was substantially containing the three primary groundwater VOC plumes at the KCP site. The planned addition of supplemental extraction wells near Outfall 001 is intended to decrease infiltration of contaminated groundwater into storm sewer lines to comply with NPDES permit effluent standards.



Effect on In Situ Contaminant Concentrations

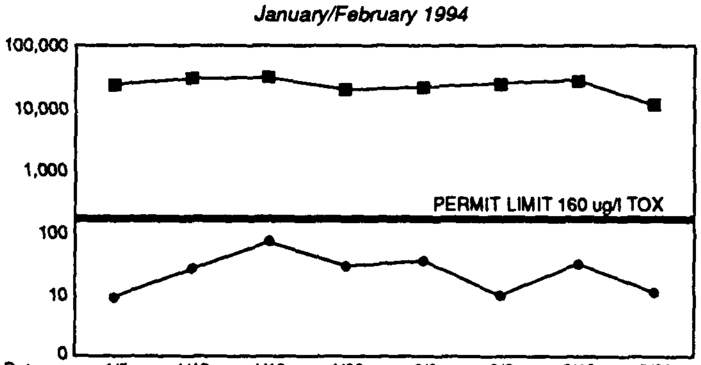
While the pump and treat system has removed a substantial mass of VOCs from the subsurface, statistically significant changes of in situ groundwater VOC concentrations have not occurred.

Treatment System Performance

• The original $UV/O_3/H_2O_2$ treatment system was replaced with the high intensity UV/H_2O_2 in May 1993 to provide capacity to treat an additional 30 GPM from the 001 Outfall Area. Despite the on-going maintenance problems, the $UV/O_3/H_2O_2$ treatment system routinely met permit discharge limits at a flow rate ~ 6 GPM from 1988 until 1990. The sewer discharge limit for total organic halogens was exceeded on 2 occasions in 1990 as a result of the adding of ~ 27 GPM of groundwater extracted from the TCE Still Area and the Outfall 001/Northeast Area. The original system was designed to handle only 25 GPM of water containing VOCs at concentrations higher than predicted by an Interim Corrective Measure Study. Aqueous-phase granular activated carbon (GAC) polishing of the $UV/O_3/H_2O$ Unit effluent was added in the late 1990 to remove residual organics prior to discharge. An in-line filter was installed and backwashing instituted to extend the life of the GAC by removing iron and manganese that precipitated following oxidation in the AOP reactor.

• Following successful completion of a rigorous acceptance testing program of the replacement UV/H_2O_2 system during late 1992, the system was placed into operation during May 1993 . As illustrated in the following graph, total VOC concentrations in the replacement system effluent have been well below the sewer discharge limit. The on-going maintenance problems experienced with the initial system have been eliminated .

UV/Peroxide Treatment System Performance



Date	1/5	1/12	1/19	1/26	2/2	2/9	2/16	2/23
Influent	23,500	30,400	31,000	19,600	21,000	23,500	26,410	10,600
Effluent	9	25	67	27	32	9	28	10

Method Detection Limit = 5 ug/l   All results ug/l total VOCs

• The initial $UV/O_3/H_2O_2$ system destroyed ~ 94.6% VOCs; ~3.7% were emitted to ambient air and ~ 1.7% were discharged to the sanitary sewer system. The replacement UV/H_2O_2 system destroyed > 99.95% VOCs; ~< 0.05% are discharged to the sanitary sewer system and there are no emissions.

• The system is designed to treat up to 30,000 ug/l. Influent averaged approximately 25,000 ug/l.

• Up to 0.3 ug/l PCBs have been detected in the UV/H_2O_2 treatment system influent. PCBs have not been detected in the treated groundwater discharged to the sanitary sewer.

Legend
Influent VOC Concentration — Effluent VOC Concentration

U.S. Air Force

COST

- Although advanced oxidation was more expensive then other alternatives such as air stripping/GAC, it was selected because of its waste minimization benefits. With advanced oxidation the contaminants are destroyed, and not transferred to another media.

- The selection of the high intensity UV/H_2O_2 treatment to replace the UV/H_2O_2 was due in part to cost savings associated with: eliminating GAC polishing, eliminating the need to treat air emissions, and reduced operation and maintenance labor and expenses.

- Capital and operating costs for the replacement UV/H_2O_2 system is presented below. Operating costs for treatment (including replacement parts, laboratory analysis, utilities, labor, and raw materials) calculated by Oak Ridge National Laboratory were $15.51/1,000 gallons for the first-generation UV/O_3/H_2O_2 demonstration unit and are projected to be $13.80/1,000 gallons for the second-generation UV/H_2O_2 replacement units once the additional 001 Outfall extraction system commences operation. The costs presented below are based on actual costs spent from fiscal years 1987 to 1994; the cost figures are not in constant dollars.

Capital Costs

Extraction Wells, Vaults, Pumps, Piping, Trenching, Electrical Conduit, & Utilities	$1,213,900
Bag Filter Units (2)	4,500
Tanks (3)	1,700
Treatment Buildings (site preparation, construction, and engineering), 3 original extraction wells	126,000
Control Systems	2,300
Equipment Installation	20,000
Startup (including acceptance testing)	15,000
Total Capital Cost	**$ 1,383,400**

Operating Costs

Electrical Power	$ 25,300
Maintenance	
Labor	52,200
Equipment Repair and Replacements[a]	3,300
Engineering Support and Project Management	44,200
Laboratory Analysis (Influent/Effluent)	78,000
Monitoring Well Analysis	110,000
Consumables	
Hydrogen Peroxide 3,600 gallons/year @ $4.00/gallon	14,400
Sulfuric Acid 3,600 gallons/year @ $1.09/gallon	3,900
Caustic 7,200 gallons/year @ $1.91/gallon	13,800
Bag Filters	700
Extraction Pump and Motor Assembly Replacement (2/year)	1,200
Transport and Disposal of Spent Filters and Personal Protective Equipment	500
Extraction Well Rehabilitations	
Chemical Treatment	5,300
Redevelopment	2,400
Total Annual Operating Cost	**$ 355,200**

[a] Average annual cost of equipment repair and replacement costs from 1983 to 1994, including costs associated with system start-up and the purchase of spare parts.

REGULATORY/INSTITUTIONAL ISSUES

• The KCP Site investigation is being performed in accordance with a U.S. Environmental Protection Agency RCRA 3008 (h) Administrative Consent Order in 1989. Initial investigation efforts, and the extraction and treatment of groundwater from the Underground Tank Farm Area were performed as voluntary actions in 1988 with EPA cognizance.

• Treatment of extracted groundwater using $UV/O_3/H_2O_2$ was initiated in 1988 as a demonstration of one of the first full-scale operating AOP systems. A rigorous program of pilot testing and long term performance monitoring was implemented to assure regulators of the effectiveness of this treatment technique and to develop data on long-term reliability and operation and maintenance costs. The second generation UV/H_2O_2 that replace the $UV/O_3/H_2O_2$ system in 1992 also underwent rigorous prove-in testing in accordance with a Startup Plan approved by EPA and the City of Kansas City, MO.

• Treated water is discharged to the municipal sanitary sewer system under the provisions of a wastewater discharge permit issued by the Kansas City Water and Pollution Control Department in February 1988. Discharge limits are summarized below:

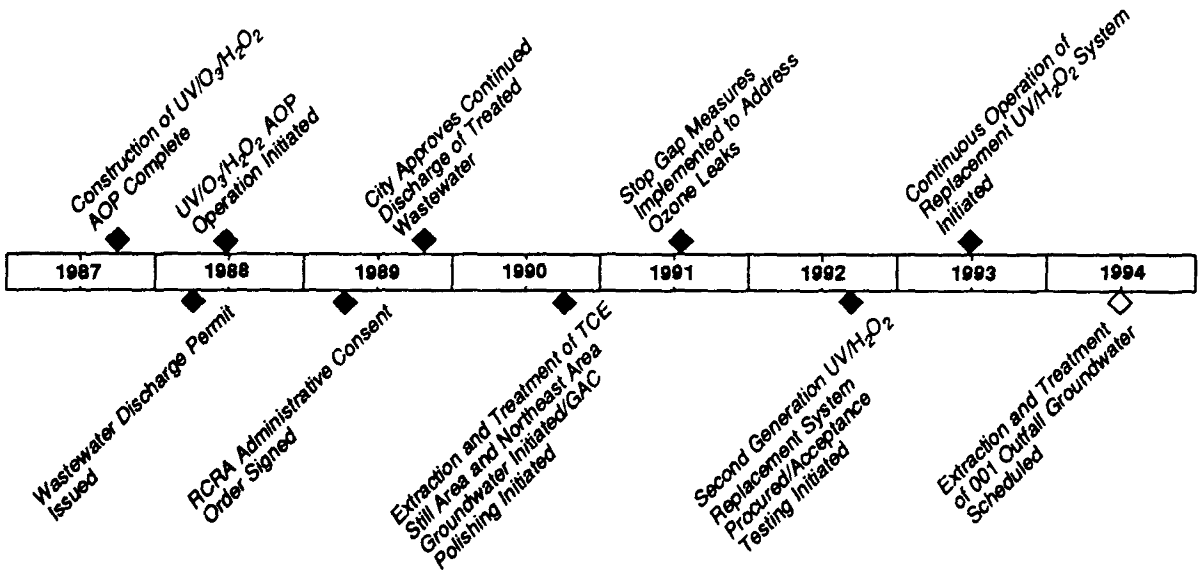
Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)
Cadmium	0.69	Arsenic	0.250
Chromium	2.77	Total Organic Halogen	0.16
Copper	3.38	Sulfides	10.0
Lead	0.69	Oil and Grease	100
Nickel	3.98	Total Cyanide	2.0
Zinc	2.61		
Iron	100.00		
Manganese	20.00		
Boron	1.00		

• Final cleanup goals have not yet been established for the site. Cleanup goals will be set subsequent to completing RFI/CMS activities.

SCHEDULE

Major Milestones

◆ *Completed Activities* ◇ *Future Activities*



• Extraction and treatment of groundwater from near the 001 Outfall will be initiated following NEPA review and obtaining approval from a railroad to a pipe groundwater beneath an active rail line that crosses the KCP site.

LESSONS LEARNED

Implementation Considerations

• An understanding of the extent of contamination at this site has evolved over a decade of investigation, monitoring, and remediation. Defining the extent of contamination has focused on determining the need for remediation in specific areas of the site, selecting and designing remedies, and evaluating the effectiveness of implemented remedial actions.

• Monitoring data and modeling results suggest that predicting the rate of aquifer restoration my be complicated due to hydrogeologic variability caused by leaking underground utilities, building footing tile drains and other anthropogenic factors and the likely presence of DNAPL(s) in a a number of areas of the site.

• Initiating an interim remedial action provided for hydraulic containment of VOCs dissolved in groundwater while the full extent of contamination and supplemental remedial actions are defined.

• Extraction flow rates must be manually adjusted at the individual well heads. The ability to control flows from the central treatment system building would eliminate difficulty in performing this task.

• Substantial and frequent fouling of the extraction system wells with bacterial slime and oxides of naturally-occurring iron and manganese have resulted in the need for frequent chemical treatment and redevelopment of wells, and repair/replacement pumps, pump motors and water level probes.

• Vaults and pipe conduits allow oxygenated rainwater to drain into extraction wells through vent tubes, contributing to the growth of bacterial slime and need for more frequent well treatment/redevelopment. Modifications made to minimize this concern have included installation of berms and drainage systems around selected well vaults. Measures to epoxy seal openings in the piping conduit are being investigated.

• The initial UV/O_3/H_2O_2 treatment system was not designed to adequately handle the flow rate and VOC concentrations realized with the interim containment system. The replacement UV/H_2O_2 treatment system was designed to handle a wider range of flow rates and concentrations to provide operational flexibility.

• The initial UV/O_3/H_2O_2 treatment system experienced significant downtime for acid cleaning of filters, ozone sparger tubes and UV lamp sheathes, and GAC backwashing/changeout. The replacement system provides for pH adjustment prior to UV/H_2O_2 treatment to minimize fouling caused in part by oxidation of inorganics.

Technology Limitations

• The initial UV/O_3/H_2O_2 treatment system was a first-generation AOP technology installed and operated at the KCP for demonstration purposes. The second-generation (replacement) AOP treatment system, operational since May 1993, has performed well at a lower cost and without the on-going maintenance problems experienced with the initial demonstration system.

• The saturated hydrocarbons present at the KCP site were readily treated by both the initial UV/O_3/H_2O_2 and the second-generation/replacement UV/H_2O_2 systems. AOP manufacturers' literature indicates that treatment efficiencies for unsaturated hydrocarbons are much lower.

• UV/H_2O_2 was selected instead of a second-generation UV/O_3/H_2O_2 AOP to replace the initial treatment system because systems that employ ozone: require more maintenance (e.g., the ozone generator and delivery system), residual ozone in the headspace of the reaction chamber is corrosive to the chamber, and catalytic oxidation is required to destroy ozone in the air discharge.

Future Technology Selection Considerations

• Greater attention should be paid to the design of extraction well systems that minimize operation and maintenance problems.

• AOP systems can destroy saturated hydrocarbons in extracted groundwater. However, designs must consider the potential for fouling with oxidized inorganics and the implementation of pretreatment measures when appropriate to ensure satisfactory performance and manageable maintenance.

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

Assistance was provided by the
ALLIEDSIGNAL INC.
which supplied key information and reviewed report drafts.

for:

HAZWRAP

HAZARDOUS WASTE REMEDIAL ACTIONS PROGRAM
Environmental Restoration and Waste Management Programs
Oak Ridge, Tennessee 37831-7606
managed by
MARTIN MARIETTA ENERGY SYSTEMS
for the
U.S. Department of Energy
under Contract DE-AC05-84OR-21400

This analysis was funded by:

U.S. Air Force
Headquarters USAF/CEVR

CERTIFICATION

This analysis accurately reflects the performance and costs of the remediation:

G.P. Keary
DOE Kansas City Plant
Environmental Restoration Program Manager

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 3, 4, 6, 7, 8, 9, and 10
Remediation System:	Source #s 1, 2, 3, 4, 5, 7, 8, 9, and 10
Performance:	Source #s 1, 2, 3, 4, 6, 7, 8, 9, 10, and 11
Cost:	Source #s 1, 2, 8, and 11
Regulatory/Institutional Issues:	Source #s 1, 3, 4, 5, 6, 9, and 11
Schedule:	Source #s 1, 2, 4, 5, 6, 7, and 10
Lessons Learned:	Source #s 1, 2, 4, 6, 7, 10, and 11

Chronological List of Sources and Additional References

1. *Kansas City Plant Groundwater Treatment System Overview,* prepared by AlliedSignal, Inc., Undated.

2. Kansas *City Plant Ultraviolet/Ozone/Hydrogen Peroxide Groundwater Treatment System Overview,* prepared by M.E. Stites, Environment, Safety and Health Department AlliedSignal, Inc., and R.F. Hughes, Energy and Environmental Systems Division, Oak Ridge Associated Universities, Undated.

3. *Tank Farm Interceptor System Evaluation and Treatment Unit Corrective Action Plan - Rev 1,* April 1991.

4. *Groundwater Interceptor System Evaluation, Kansas City Plant,* prepared by Department of Energy, Albuquerque Operations Office, Environmental and Health Division, Environmental Programs Branch, May 1992.

5. *Groundwater Treatment System Interim Measures Plan, U.S. DOE Kansas City Plant,* revised August 1993.

6. *TCE Still Area RCRA Facility Investigation Report - Draft, Kansas City Plant,* prepared by Department of Energy, Albuquerque Operations Office, Environmental and Health Division, Environmental Programs Branch, Environmental Restoration Program, September 1993.

7. *Kansas City Plant Groundwater Remediation,* prepared by AlliedSignal, Inc., October 15, 1993.

8. *Northeast Area/001 Outfall Corrective Measure Study - Draft, Kansas City Plant,* prepared by Department of Energy, January 1994.

9. *Annual Groundwater Monitoring Report for Calender Year 1993, Kansas City Plant,* prepared by Department of Energy, Albuquerque Operations Office, Environmental Programs Branch, Environmental Restoration Program, March 1994.

10. *Data Package Supplied by Mr. Michael E.* Stites, AlliedSignal, Inc., April 25, 1994.

11. *Personal Communications with Michael E. Stites and Joseph L. Baker,* AlliedSignal, Inc. May and June 1994.

Pump and Treat of Contaminated Groundwater at U.S. Department of Energy Savannah River Site, Aiken, South Carolina (Interim Report)

Case Study Abstract

Pump and Treat of Contaminated Groundwater at U.S. Department of Energy Savannah River Site, Aiken, South Carolina

Site Name:
U.S. Department of Energy (DOE)
Savannah River Site A/M Area

Contaminants:
Chlorinated Aliphatics
- Trichloroethene (TCE), Tetrachloroethene (PCE), and 1,1,1-Trichloroethane (TCA)
- Concentrations of volatile organic compounds (VOCs) in groundwater reported as high as 500 ppm
- Groundwater TCE concentrations over 48 ppm
- Groundwater contains 260,000-450,000 pounds of dissolved organic solvents in concentrations greater than 0.01 ppm, estimated to be 75% TCE
- Soil TCE concentrations over 10 ppm
- Dense nonaqueous phase liquids (DNAPLs) are present in groundwater

Period of Operation:
Status: Ongoing
Report covers - 9/85 to 12/93

Location:
Aiken, South Carolina

Cleanup Type:
Full-scale cleanup (interim results)

Vendor:
C.L. Bergen
Westinghouse Savannah River Company
Aiken, SC

Technology:
Groundwater Extraction Wells followed by Air Stripping
- 11 recovery wells at depths to over 200 feet below ground surface
- Production air stripper has a design capacity of 610 gpm; operated at 510 gpm
- 1993 average flow rate was 479 gpm; average air flow rate was 2,489 cfm
- In 1993, 19,500 lbs of VOCs removed; average air emission rate of 2 lbs/hr

Cleanup Authority:
RCRA Corrective Action and State: South Carolina Bureau of Air Quality Control

SIC Code:
9711 (National Security)
3355 (Aluminum forming)
3471 (Metal finishing)

Point of Contact:
G.E. Turner, DOE
Savannah River Oper. Office
Environmental Restoration Div.
Aiken, SC

Waste Source:
Surface Impoundment

Type/Quantity of Media Treated:
Groundwater
- VOC contaminated groundwater has an approximate thickness of 150 ft and covers about 1,200 acres
- Complex hydrogeology arising from heterogeneities in a multilayer aquifer system with discontinuous sand and clay layers
- Hydraulic conductivity 9 - 73 ft/day
- Transmissivity 175 - 12,500 gpd/day

Purpose/Significance of Application:
Full-scale pump and treat remediation of groundwater contaminated with VOCs using aboveground air stripping.

Pump and Treat of Contaminated Groundwater at U.S. Department of Energy Savannah River Site, Aiken, South Carolina (Continued)

Regulatory Requirements/Cleanup Goals:
Groundwater:
TCE - 5 ppb; PCE - 5 ppb; TCA - 200 ppb
- Adopted in 1990, based on EPA MCLs
- During initial remediation efforts in 1985, the cleanup goal was 99% removal of VOCs over a 30-year period

Air:
34 tons/yr VOCs or 7.9 lbs/hr
- Based on South Carolina Bureau of Air Quality Control permit

Results:
As of 1993:
- Influent concentrations to air stripper decreased for TCE (from 25,000 ppb to about 6,000 ppb) and PCE (from 12,000 ppb to 4,000 ppb)
- The total quantity of VOCs removed from 1985 to 1993 is 273,300 lbs
- Average VOC removal efficiency for air stripper >99.9%

Cost Factors:
- Total Capital Costs (1990 dollars) - $4,103,000 (including design, construction and installation, engineering, site development)
- Total Annual Operating Costs (1990 dollars) - $149,200 (for years 1985 to 1990) (including electricity, maintenance, operation, well sampling and analysis)
- Total cost of operation and maintenance is $0.75 per 1,000 gallons treated (198 million gallons per year treated)
- An estimated total cost for completing the cleanup is not available at this time

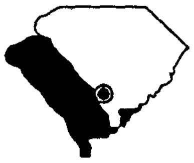
Description:
At the U.S. Department of Energy Savannah River Site, administrative buildings are located within the "A" area and aluminum forming and metal finishing operations have been performed within the "M" area. An estimated 3.5 million pounds of solvents were discharged from these operations between 1958 and 1985, with over 2 million pounds sent to an unlined settling basin. Groundwater contamination beneath the settling basin was discovered in 1981. The primary contaminants were volatile organic compounds (VOCs) at concentrations up to 500 ppm. A pilot groundwater remediation system was operated in 1983, with the full-scale groundwater treatment begun on September 1985. The full-scale technology included groundwater extraction wells and a production air stripper. The design of the production air stripper was based on pilot and prototype air strippers.

While the remediation was ongoing at the time of this report, reductions in concentrations of both TCE and PCE to the air stripper have been noted and the estimated total historical (1985 to 1993) removal of VOCs is over 273,000 lbs. In addition, the average VOC removal efficiency of the air stripper is greater than 99.9%. Contaminated groundwater in the source areas and the areas of the highest VOC concentrations appears to be contained at this time. However, the areas at the fringes of the plume are not as well contained, due to hydraulic factors.

The total capital cost for this application is $4,103,000 and the total annual operating costs are $149,200. DNAPLs were discovered in the groundwater in 1991 and pose a significant limitation to the long-term use of pump and treat, since pump and treat is effective for plume restoration only where DNAPL source areas have been contained or removed. A need for supplemental site characterization to fully define the DNAPL contamination and to redirect ongoing remediation activities has been identified.

SITE

U.S. Department of Energy
Savannah River Site
A/M Area
Aiken, South Carolina



TECHNOLOGY APPLICATION

This analysis covers an effort to **pump and treat groundwater** contaminated with volatile organic compounds **(VOCs)** by above ground **air stripping.** Full scale treatment began in September 1985 and is one component of an ongoing environmental restoration program. This analysis covers performance through December 1993.

SITE CHARACTERISTICS

Site History/Release Characteristics

- The Savannah River Site's historical mission has been to support national defense efforts through the production of nuclear materials. Production and associated research activities have resulted in the generation of hazardous waste byproducts now managed as 266 waste management units located throughout the 300 square mile facility.
- The A and M areas at Savannah River have been the site of administrative buildings and manufacturing operations respectively. The Savannah River Laboratory is also located within the A area. Specific manufacturing operations within the M area include aluminum forming and metal finishing.
- The M area operations resulted in the release of process wastewater containing an estimated 3.5 million pounds of solvents. From 1958 to 1985, 2.1 million pounds was sent to an unlined settling basin which is the main feature of the M-Area Hazardous Waste Management Facility (HWMF). The remaining 1.3 million pounds was discharged to Tims Branch, a nearby stream, during the years 1954 to 1982.
- Discovery of contamination beneath the settling basin in 1981 initiated a site assessment effort eventually involving approximately 250 monitoring wells over a broad area. A pilot groundwater remediation system began operation in February 1983. Full-scale groundwater treatment began in September 1985.

Contaminants of Concern

Contaminants of greatest concern in the groundwater are:

1,1,2-trichloroethylene (TCE)
tetrachloroethylene (PCE)
1,1,1-trichloroethane (TCA)

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Property at STP*	Units	TCE	PCE	TCA
Empirical Formula	-	$ClCH{=}CCl_2$	$Cl_2C{=}CCl_2$	CH_3CCl_3
Density	g/cm^3	1.46	1.62	1.31
Vapor Pressure	mmHg	73	19	124
Henry's Law Constant	$atm{\cdot}m^3/mole$	9.9E-3	2.9E-3	1.6E-2
Water Solubility	mg/L	1000-1470	150-485	300-1334
Octanol-Water Partition Coefficient; K_{ow}	-	195	126	148

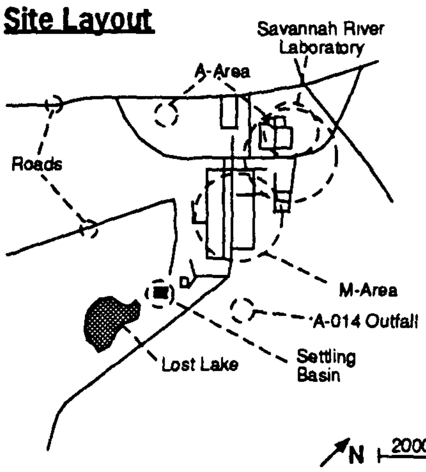
**STP = Standard Temperature and Pressure; 1 atm, 25 °C*

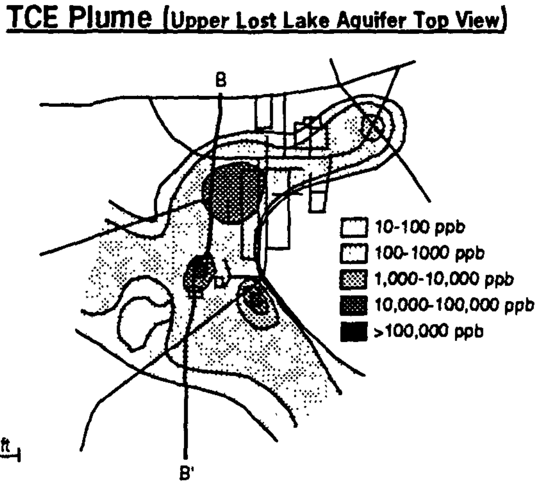
Nature & Extent of Contamination

- Approximately 71% of the total mass of VOCs released to both the settling basin and Tims Branch was PCE, 28% was TCE and 1% was TCA.
- The dissolved organic solvents are estimated to be 75% TCE. A continued source for dissolved phaseVOCs is contaminants sorbed to solids in the saturated zone or in the vadose zone.
- The area of VOC contaminated groundwater has an approximate thickness of 150 feet, covers about 1200 acres and contains contaminant concentrations as high as 223 ppm.
- Dense nonaqueous phase liquids (DNAPLs) were found in 1991 and present complications to long term remediation efforts.

Contaminant Locations and Geologic Profiles

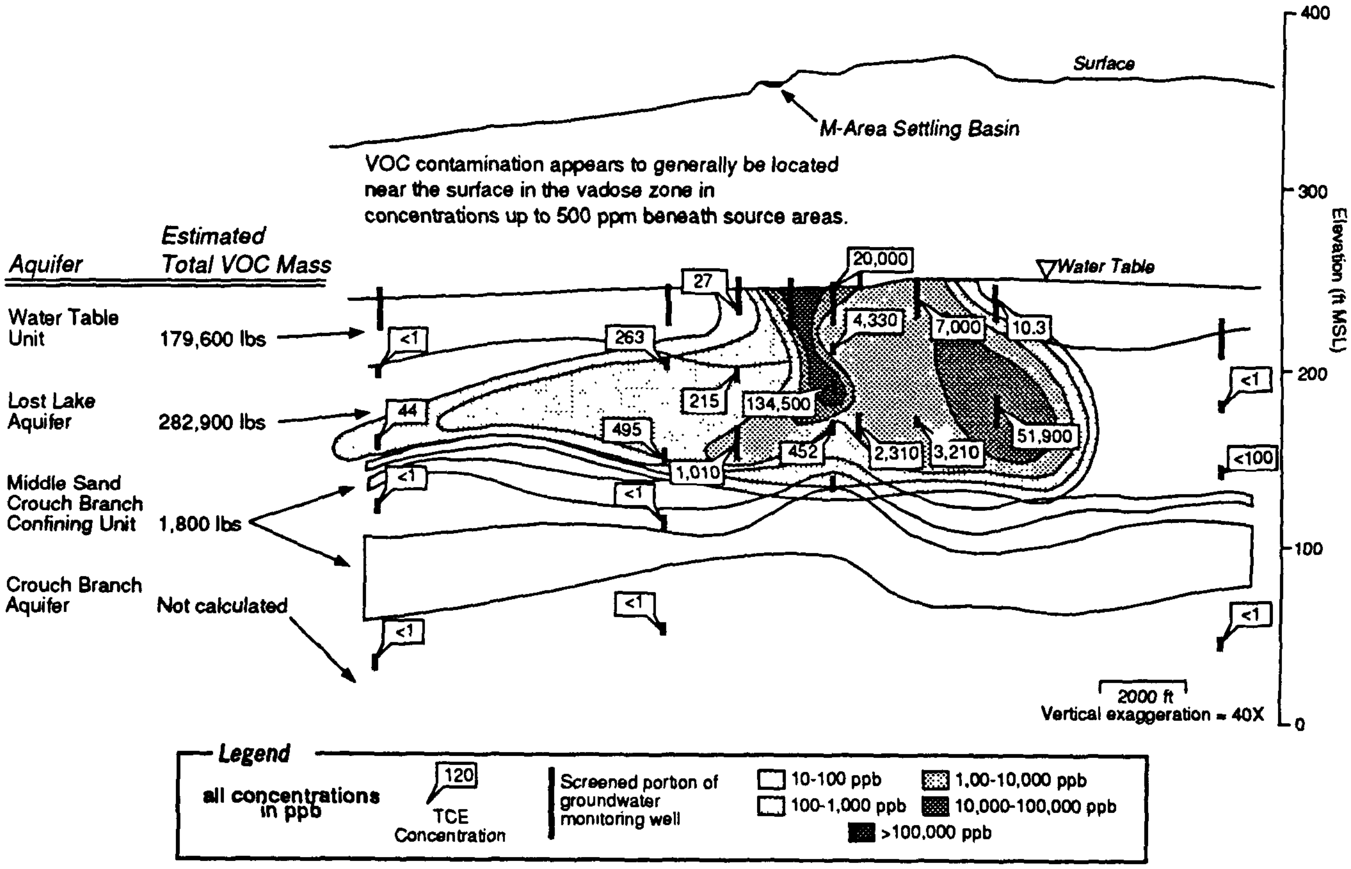
Data from hundreds of soil borings, groundwater monitoring wells and a variety of other investigative techniques has allowed the development of a three dimensional conceptual model of the site including groundwater behavior and contaminant concentration profiles for various geologic units. The following diagrams have been included here to provide a general understanding of site conditions. Data from the third quarter of 1985 is presented.





TCE Plume (Side View)

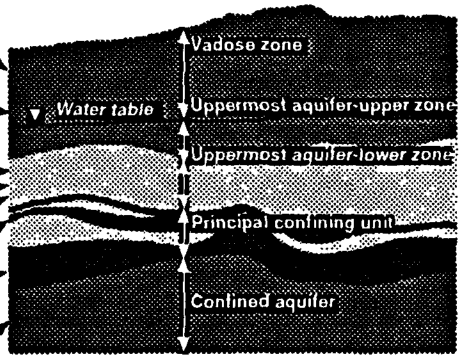
Groundwater monitoring data from the third quarter of 1985 along cross-section B-B' shown in top view



Contaminant Locations and Geologic Profiles (Continued)

Hydrogeologic Units

Aquifer	Subunit	Description	Thickness
	Upland	Poorly sorted mix of sand, cobbles, silt & clay.	~57 ft
	Tobacco Road	Moderate to well sorted, fine to medium sand containing some pebbles; 13% silt & clay.	0-97 ft
	Dry Branch	Moderately to well sorted medium sand; 18% silt & clay.	30-55 ft
Water Table Unit		Moderate to well sorted fine sand with some calcareous zones; 25% silt & clay; 14% silt and clay beds.	16-34 ft
Lost Lake Aquifer	Upper	Well sorted fine to medium sand; 16% silt & clay; 7% silt & clay beds.	14-60 ft
Discontinuous clay beds containing 70% silt & clay			
	Lower	Moderate to well sorted medium sand; 17% silt & clay; 7% silt & clay beds.	4-44 ft
Crouch Branch Confining Unit		Clay, clayey silt, and poorly sorted fine to coarse, clayey sand; 62% silt 7 clay; contains 2 major clay layers the lower of which is 10-56 ft thick and is the principal confining unit for the Black Creek Formation.	32-95 ft
Crouch Branch Aquifer		Very poorly to well sorted, medium to coarse sands; 5% sand & clay beds; an important production zone for water supply wells in the M-Area.	152-180 ft



Site Conditions

- The A/M-Area is approximately one mile inward from the northeast boundary of the 300 square mile Savannah River Site. Adjacent to the site boundary are rural and farming communities.
- The Savannah River Site includes a complex hydrogeology arising from heterogeneities in the multilayer aquifer system and discontinuous sand & clay layers.

Key Aquifer Characteristics

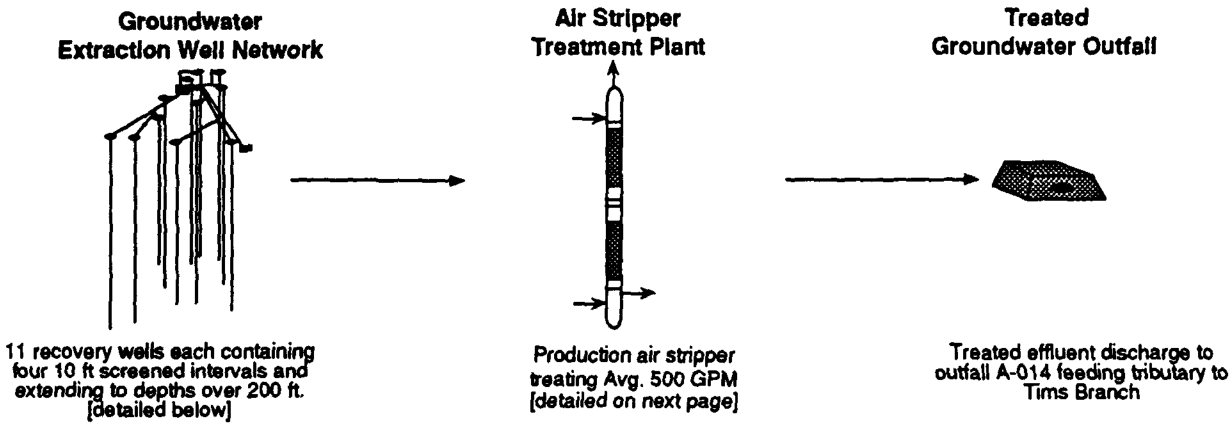
Aquifer parameters beneath the A/M-Area have been estimated as:

Unit	Hydraulic Conductivity [ft/day]	Transmissivity [gpd/day]	Flow Direction
Water Table Unit	9	175	Flow in the unconfined water table unit within the McBean Formation is complex but radial flow is expected outward from a plateau (at 244 MSL) surrounding most of the A/M-Area.
Lost Lake Aquifer	Avg. 40	Avg. 1750	Ranged from southwest to northeast near the A/M-Area in the Upper Lost Lake. Mainly east and south in the Lower Lost Lake during 1985-86.
Middle Sand Crouch Branch Confining Unit	29	1600	Mainly southeast during 1985-86.
Crouch Branch Aquifer	73	12,500	Mainly southeast during 1985-86.

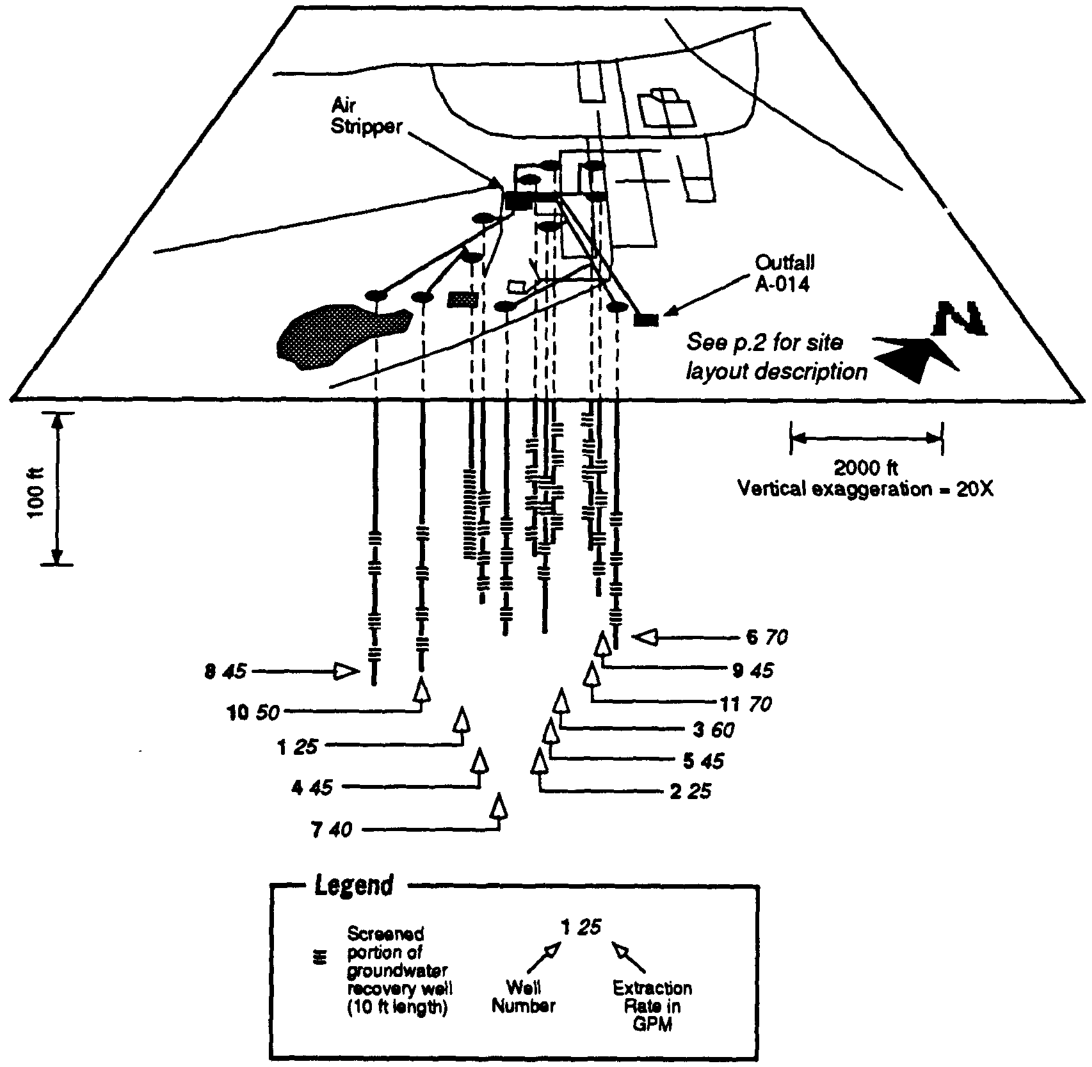
- A wide range of values has been used to describe regional aquifer characteristics. Uncertainties stem from difficulties in aquifer testing and interpretating methods applied to the hydrogeological complexities noted above under Site Conditions.
- A moderate downward gradient appears to exist beneath the M-Area. Vertical flow rates have been estimated to be from 2 to 8 feet per year.
- Radial flow outward from a groundwater plateau surrounding most of the A/M-Area within the water table unit and Upper Lost Lake aquifer is approximately 15 to 100 ft/year.

TREATMENT SYSTEM

Overall Process Schematic

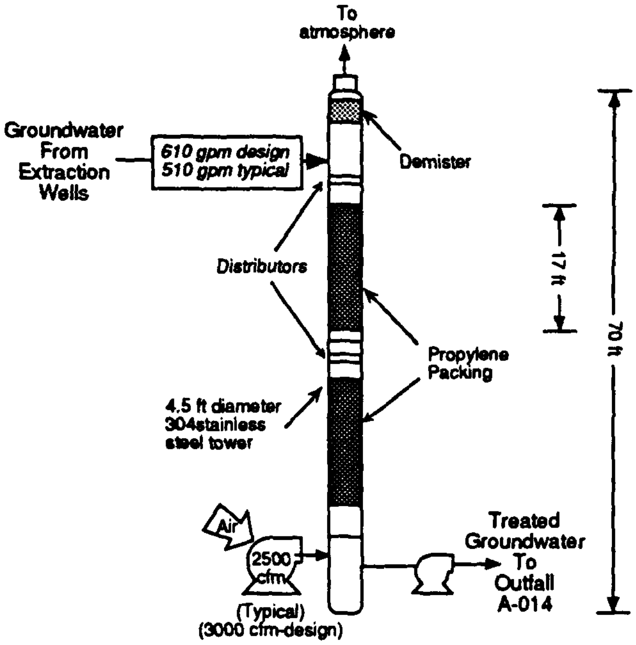


Extraction Well Network

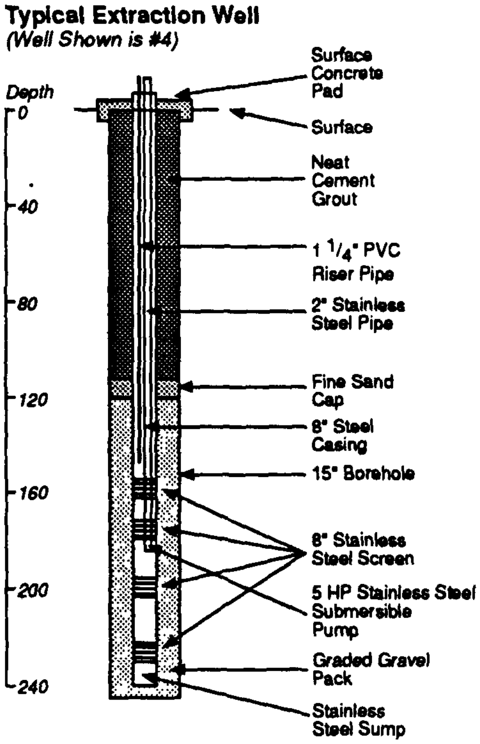


Air Stripper System Schematic

- In 1988, the original pall ring packing was replaced with cascade mini-rings to provide more surface area and less pressure drop across the system.
- In 1990, system in flow was upgraded from 400 gpm to 510 gpm.
- Drawing not to scale.



Extraction Well Close-Up



Key Monitored Operating Parameters

- Water flows
- Air flows

(to assess system operation)

- Pump discharge pressures
- Groundwater levels

  (to assess zone of capture)
- Contaminant concentrations in treatment plant influent & effluent

  (to assess treatment effectiveness)
- Contaminant concentrations in groundwater

  (to assess achievement of remediation goals)

PERFORMANCE

Performance Objectives

• Achievement of Groundwater Protection Standards (GWPS) established as part of a RCRA permit for the M-Area. The GWPS are based on EPA's Maximum Contaminant Levels (MCLs) of 5 ppb for TCE and PCE and 200 ppb for TCA.

• Prevent migration of contaminated groundwater toward the Savannah River Site boundary and downward into the confined aquifer (Black Creek Formation).

• Achieve cleanup goals within 30 years.

Treatment Plan

The overall long-term environmental restoration strategy for the A/M-Areas involves an integrated approach containing three major elements. Only the larger A/M air stripping effort is fully detailed in this analysis:

• Operation of **pump-and-treat** systems to hydraulically **contain** contaminant plumes and **remove contaminant mass** from groundwater.

One 600 GPM capacity air stripper treats an average water flow of 510 GPM drawn from 11 extraction wells throughout the A/M area; a second stripper treating an average of 55 GPM from 1 extraction well near the Savannah River Laboratory in the A-Area.

• **Further characterization** of nature and extent of contamination with increasing focus on dense nonaqueous phase liquid (**DNAPL**) contamination.

The use of minimally invasive techniques, such as the cone penetrometer and geophysical techniques, are currently recommended for future use to fully characterize the extent of DNAPL contamination.

• Development, demonstration and implementation of **technologies to supplement pump-and-treat** efforts with increasing focus on **source area, DNAPL and vadose zone** remediation.

Soil vapor extraction, in situ air stripping, in situ heating, and surfactant flushing techniques are in various stages of implementation or demonstration.

Initial Process Optimization Efforts

Air stripper viability was tested through a succession of field programs:

Pilot Air Stripper	→	Prototype Air Stripper	→	Full Scale Production Air Stripper
Constructed and operated for 24 months beginning in 1983; 34 ft high; 20 GPM capacity; removed 16,100 lbs VOCs.	→	Stainless steel construction; operated for 14 months; 46 ft high; 50 GPM capacity; removed 15,800 lbs of VOCs.	→	Stainless steel construction; 70 ft high, 610 GPM design capacity; removed 270,000 lbs of VOCs since startup in 9/85.

Operational Performance

System Throughput

• For 1993, 243 million gallons of groundwater were pumped from 11 recovery wells to the production air stripper.

• Average water flow rate was 479 GPM and average air flow rate was 2,489 cfm through the air stripper during 1993.

• 19,500 lbs of VOCs were removed in 1993 which produced an average air emission rate of 2 lbs/hr.

System Downtime

• Average utility for 1993 was 96.4%. Cumulative average utility since 1985 is 95.3%.

• 1993 experienced 316 hours of downtime.

• Causes of downtime included scheduled maintenance, operator training, power outages, and equipment repair.

Hydrodynamic Performance

• Current estimates of the 30 year zone of capture of the pump and treat system have determined that portions of the existing plume will not be effectively controlled. Contaminated groundwater beneath the Savannah River Laboratory and southeast of the settling basin are beyond the anticipated capture zone. However, contaminated groundwater in the source areas and areas of highest VOC concentration is contained.

• The downward gradient across the Crouch Branch Confining Unit, and consequently the driving force for downward contaminant migration to the confined aquifer in the Crouch Branch Aquifer, has been reduced due to pumping effects.

• The groundwater recovery wells are screened in the more permeable areas of the shallow aquifer which increase hydraulic control yet limits access to silt and clay layers where retention of contaminants may be strongest.

Treatment Performance

Effects on Plume

• Reductions in contaminant plume size and concentration as a result of remediation are evident (the >100,000 ppb contaminant concentration zone has disappeared) but are generally limited to areas near recovery wells.

• Significant progress is evident in the Lost Lake Aquifer where initial contaminant concentration and hydraulic conductivity are highest.

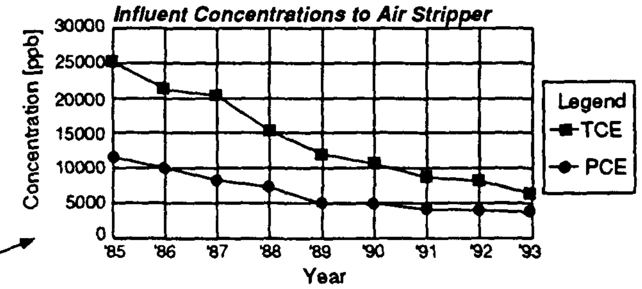
• Downward migration of VOCs to the Crouch Branch Aquifer beneath the settling basin and north of the M-Area is evident. VOC concentrations have increased slightly in the confined aquifer since 1985.

TCE & PCE vs Time at Influent

• The concentration of TCE in extracted groundwater has varied widely over short (one year) time frames for individual wells. Some wells have shown short term increases in contaminant concentration, some decreases and others no clear trend.

• The trends may indicate plume redistribution and may also represent a decline in plume strength.

• There has been a clear reduction in overall contaminant concentrations sent to the air stripper.



Air Stripper Influent vs Effluent

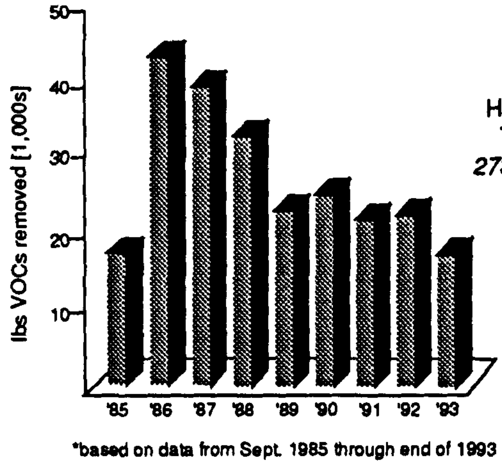
• Average VOC removal efficiency >99.9%

• All VOCs treated below discharge criteria.

Compound	Average Concentration* [ppb] Influent	Effluent
TCE	15,006	<1.01
PCE	6,705	<1.0
Total	21,711	<1.12

*data from September 1985-1993

Total Pounds VOCs Removed



Historical Total*: *273,300 lbs*

*based on data from Sept. 1985 through end of 1993

COST

• The production air stripper was designed and constructed in 1984-1985. The major capital cost elements associated are provided below. Annual operating costs based upon data from 1985 through 1990 are also listed. All information is based on an analysis performed in 1990 and all costs are in 1990 dollars.

• During 1985 to 1990, the average volume of water treated by the air stripper was 198 million gallons per year. Using the operating costs detailed below (in 1990 dollars), the total cost of operation and maintenance is $0.75 per 1000 gallons treated.

• An assessment of total cost and duration of operation for the pump and treat system to complete the cleanup is not possible due to the multi-phased approach to environmental restoration of the A/M Area. As detailed on page 6, the overall treatment plan for the site includes future identification and implementation of technologies to achieve cleanup goals. The extent to which the pump and treat system will be part of that effort has not yet been determined therefore projected costs to cleanup can not be estimated.

Capital Costs

Design	$420,000
Contracts (permitting, modeling, etc.)	368,000
Site Development	28,000
QA Engineering	18,000
Control Building	211,000
Electrical	877,000
Instrumentation	466,000
Piping/Construction	925,000
Tower Installation	132,000
Control System	230,000
Erect/Test Tower	428,000
Total	**$4,103,000**

Operating Costs

Electrical Power (@ $0.052/kwh)	$26,000
Maintenance	
Labor (@ $35/hr)	13,500
Equipment repair & replacement	13,000
Operation	
Operation & daily inspections	45,700
Well sampling & lab analysis	15,000
Engineering support	36,000
Total Annual Operating Cost	**$149,200**

REGULATORY/INSTITUTIONAL ISSUES

- The production air stripper is part of the M-Area Hazardous Waste Management Facility which is permitted under the Resource Conservation and Recovery Act (RCRA). The air stripper unit is permitted as a waste water treatment facility requiring South Carolina certified Class-D physical/chemical operators. The air stripper unit is not regulated as a RCRA treatment, storage, disposal (TSD) facility.

- The air stripper has a South Carolina Bureau of Air Quality Control permit allowing the release of 34 tons/year (or 7.9 lbs/hr) of VOCs to the atmosphere.

- Recent Clean Air Act requirements mandate that industrial off gas systems be retrofitted with an off-gas treatment system. Catalytic oxidation has been demonstrated as an effective off-gas treatment and the M-Area air stripper is being retrofitted. The system will be installed by 1995, even though regulations for mitigation will not require retrofit until 2000.

- Treated water effluent from the stripper is released through an National Pollution Discharge Elimination System (NPDES) permitted outfall. The EPA Maximum Contaminant Levels (MCLs) listed under "Cleanup Criteria" below apply to this discharge.

- The facility's RCRA Part B permit requires periodic sampling at the recovery wells, air stripper and NPDES outfall.

- Eight production wells drawing from the Crouch Branch Confined Aquifer currently supply process and drinking water for A/M-Area Site operations.

Cleanup Criteria

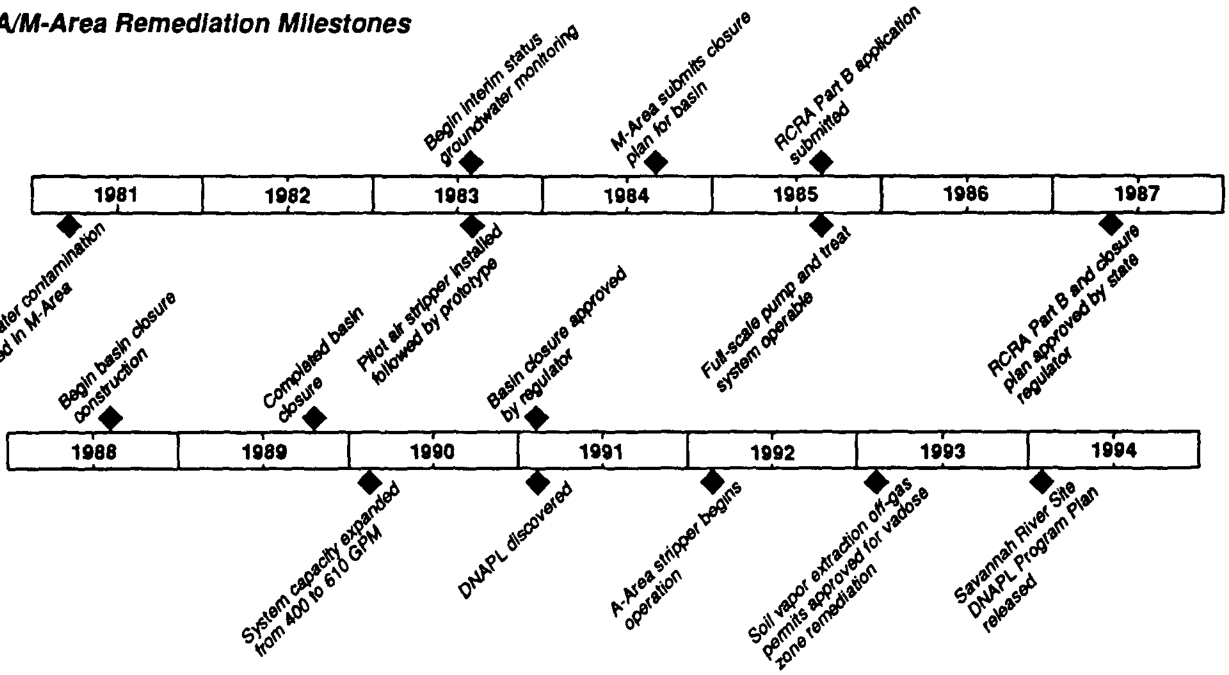
- During initial remediation efforts in 1985, a cleanup goal of removal of 99% of VOCs over a 30 year period was used. A CERCLA baseline risk assessment was not developed or required.

- In 1990, groundwater protection standards based upon EPA MCLs were adopted during modifications of the facility's RCRA permit. The standards are:

Compound	Criteria Level [ppb]
TCE	5
PCE	5
TCA	200

SCHEDULE

A/M-Area Remediation Milestones



LESSONS LEARNED

Implementation Considerations

• An integrated treatment program consisting of pump and treat for hydraulic control and dissolved plume mass removal combined with source/DNAPL targeted technologies has been determined to be the most effective long term remedial solution for the M-Area VOC plume at Savannah River.

• Technologies to supplement the pump and treat systems are in various stages of development, demonstration or implementation. These technologies focus on either the source area, DNAPL or vadose zone contamination and include soil vapor extraction, in situ air stripping, in situ bioremediation, in situ heating and surfactant flushing.

• There is a recognized need for supplemental site characterization efforts to redirect ongoing remediation activities at the site. Further characterization will focus on DNAPL contamination and will involve minimally invasive methods such as the cone penetrometer and geophysical techniques.

• Significant volumes of VOC-contaminated purge water are generated from sampling the extensive network of over 250 monitoring and compliance wells. Modifications to the air stripping system were implemented to treat this groundwater. The system changes include addition of a 10,000 gallon carbon steel receiving tank and associated piping.

Technology Limitations

• The presence of DNAPLs represents a significant long-term limitation to pump and treat due to residual DNAPL above and below the water table combined with mass removal limitations.

• Hydraulic factors, combined with the nature of contaminants, has inhibited the pump and treat system's ability to affect the fringes of the plume. However, the contaminated groundwater in the source areas and areas of highest VOC concentration is contained.

• Pump and treat is effective for plume restoration only where DNAPL source areas have been contained or removed.

Future Technology Selection Considerations

• Early M-Area remediation efforts did not address the long term prospect of removing residual levels of contamination. Future cleanups at sites with chlorinated solvents must carefully look for DNAPL during site characterization and address DNAPL and residual contamination removal as part of an overall remediation plan.

• The original aim of the pump and treat system in the M-area was for broad plume containment and destruction of 99% of the VOCs. This goal was later changed to achievement of EPA MCL based groundwater protection standards. Future pump and treat systems should consider the actual environmental and human risks, be highly designed, and address realistic elements of overall cleanup goals.

• Pump and treat for containment of dissolved contaminants is a viable tool for dissolved phase VOC removal and can be an element of presumptive remedies for such sites.

• A phased approach to site assessment and remediation is beneficial. Early actions to control plume migration and remove contaminant sources, when properly designed and implemented, can reduce risks posed by contaminated groundwater.

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

Assistance was provided by the
WESTINGHOUSE SAVANNAH RIVER COMPANY
which supplied key information and reviewed report drafts.

for:

HAZWRAP

HAZARDOUS WASTE REMEDIAL ACTIONS PROGRAM
Environmental Restoration and Waste Management Programs
Oak Ridge, Tennessee 37831-7606
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for the
U.S. Department of Energy
under Contract DE-AC05-84OR-21400

This analysis was funded by:

U.S. Air Force
Headquarters USAF/CEVR

CERTIFICATION

This analysis accurately reflects the performance and costs of the remediation:

x	x
C.L. Bergren	G.E. Turner
Westinghouse Savannah River Company	Department of Energy
Environmental Restoration Department	Savannah River Operations Office
Manager Northern Ground Water Facilities	Environmental Restoration Division
	Environmental Specialist

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 5,7,8 and 9
Treatment System:	Source #s 5,6 and 7
Performance:	Source #s 1,2,3,5 and 7
Cost:	Source # 5
Regulatory/Institutional Issues:	Source # 5
Schedule:	Source #s 1,5, and 7
Lessons Learned:	Source #s 1,3, and 4.

Chronological List of Sources and Additional References

1. *Personal communications with J.E. Jordan*, Westinghouse Savannah River Company, April 1994.

2. *Corrective Action System Operation and Performance (Draft)*, Fourth Quarter 1993 and 1993 Summary, WSRC-RP-93-67-4, February 1994.

3. *Savannah River Site DNAPL Technical Program Plan*, J.E. Jordan, et.al., Westinghouse Savannah River Company, February 1994.

4. *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration*, Interim Final, U.S. EPA, September 1993.

5. McKillip, S.T., K.L Sibley and J.G. Horvath, *Air Stripping of Volatile Organics Chlorocarbons: System Development, Performance, and Lessons Learned*, Proceedings of Waste Managment '90, Roy Post, editor, 1990.

6. *Well logs for recovery wells (undated).*

7. *Evaluation of Ground-water Extraction Remedies: Phase II* EPA Publication 9355.4-05A, February 1992.

8. *Evaluation of Ground-water Extraction Remedies*, EPA/540/2-89-054, September 1989.

9. *Preliminary Technical Data Summary M-Area Groundwater Cleanup Facility*, DuPont - Savannah River Laboratory, October 1982.

In Situ Air Stripping of Contaminated Groundwater at U.S. Department of Energy, Savannah River Site Aiken, South Carolina

Case Study Abstract

In Situ Air Stripping of Contaminated Groundwater at U.S. Department of Energy, Savannah River Site Aiken, South Carolina

Site Name: U.S. Department of Energy (DOE), Savannah River Site M Area, Process Sewer/Integrated Demonstration Site **Location:** Aiken, South Carolina	**Contaminants:** Chlorinated Aliphatics - Trichloroethene (TCE), Tetrachloroethene (PCE), 1,1,1-Trichloroethane (TCA) - Concentrations of volatile organic compounds (VOCs) in groundwater reported as high as 1800 µg/L - Groundwater TCE concentrations over 48 ppm - Groundwater contains 260,000-450,000 pounds of dissolved organic solvents in concentrations greater than 0.01 ppm, estimated to be 75% TCE - Soil TCE concentrations over 10,000 µg/L (1991) - Dense nonaqueous phase liquids (DNAPLs) are present in groundwater	**Period of Operation:** July 1990 to September 1993 **Cleanup Type:** Field Demonstration
Technical Information: Brian Looney, Principal Investigator, Westinghouse Savannah River Company (WSRC), (803) 725-3692 Carol A. Eddy Dilek, WSRC (803) 725-2418 Kurt Gerdes, DOE EM-50, (301) 903-7289 Dawn Kaback, Colorado Center for Environmental Management, (303) 297-0180, ext. 111 **SIC Code:** 9711 (National Security) 3355 (Aluminum forming) 3471 (Metal finishing)	**Technology:** In Situ Air Stripping - 7 horizontal wells installed; only 2 wells used in field demonstration - Demonstration wells: 1 installed in saturated zone; 1 installed in vadose zone; targeted contaminated sands - Air injected through lower horizontal well, below the water table - Demonstration focused on supplementing pump and treat efforts - Demonstration did not include offgas treatment	**Cleanup Authority:** RCRA Corrective Action and State: South Carolina Dept. of Health and Environmental Control, Air Quality Control, and Underground Injection Control **Licensing Information:** Caroline Teelon Tech Transfer Office, WSRC P.O. Box 616, Building 77341A Aiken, SC 29803 (803) 725-5540
Waste Source: Surface Impoundment	**Type/Quantity of Media Treated:** Groundwater and Soil - Area of VOC-contaminated groundwater has an approximate thickness of 150 feet and covers about 1,200 acres - Aquifer units characterized to 180 feet below ground surface (9 separate units), showing complex hydrogeology and discontinuous sand and clay layers	
Purpose/Significance of Application: Field demonstration of in situ air stripping using horizontal wells to supplement groundwater pump and treat technology.		

In Situ Air Stripping of Contaminated Groundwater at U.S. Department of Energy, Savannah River Site Aiken, South Carolina (Continued)

Regulatory Requirements/Cleanup Goals:
- RCRA permit for M Area includes the following Groundwater Protection Standards: TCE 5 ppb, PCE 5 ppb, and TCA 200 ppb
- Demonstrations permitted by the South Carolina Department of Health and Environmental Control (SCDHEC) Air Quality Control (AQC) and Underground Injection Control (UIC)

Results:
- Substantial changes in groundwater VOC concentrations measured during demonstration
- Increased microbial numbers and metabolic activity exhibited during air injection period
- 139 day demonstration (July-December 1990) removed nearly 16,000 pounds of VOCs
- Vacuum extraction removed an estimated 109 lbs VOC/day while air injection resulted in an additional 20 lbs/day VOC removal

Cost Factors:
- Costs for conducting field demonstration not provided

Cost study for in situ air stripping provided the following projected costs:
- Total equipment costs - $253,525 (including design and engineering, well installation, air injection and extraction system, piping, and electrical)
- Site costs - $5,000 (setup and level area)
- Total Annual Labor Costs - $62,620 (including mobilization/demobilization, monitoring, and maintenance)
- Total Annual Consumable Costs $157,761 (including carbon recharge, fuel, and chemical additives)

Description:
At the U.S. Department of Energy Savannah River Site, aluminum forming and metal finishing operations have been performed within the "M" area. An estimated 3.5 million pounds of solvents were discharged from these operations between 1958 and 1985, with over 2 million pounds sent to an unlined settling basin. Groundwater contamination beneath the settling basin was discovered in 1981. A pump and treat program has been ongoing since 1985 for removal of VOCs from the groundwater.

A field demonstration using in situ air stripping with horizontal wells in the M Area was conducted from July 1990 to September 1993. The demonstration was part of a program at Savannah River to investigate the use of several technologies to enhance the pump and treat system. In the air stripping demonstration, air was injected into a lower horizontal well in the saturated zone and extracted through the horizontal well in the vadose zone. The demonstration did not include treatment of offgases. The in situ air stripping process increased VOC removal over conventional vacuum extraction from 109 pounds per day to 129 pounds per day. Nearly 16,000 pounds of VOCs were removed during the 139 day demonstration period.

A cost analysis performed as part of this demonstration showed that in situ air stripping would reduce costs by 40% over a conventional pump and treat with soil vapor extraction system. Installation costs for horizontal wells is greater than for vertical wells. At depths greater than 40 to 50 ft, horizontal well installation costs are approximately $200/ft; at less than 40 to 50 ft, costs are as low as $50/ft. Several implementation concerns were identified for installing horizontal wells at Savannah River.

SECTION 1

SUMMARY

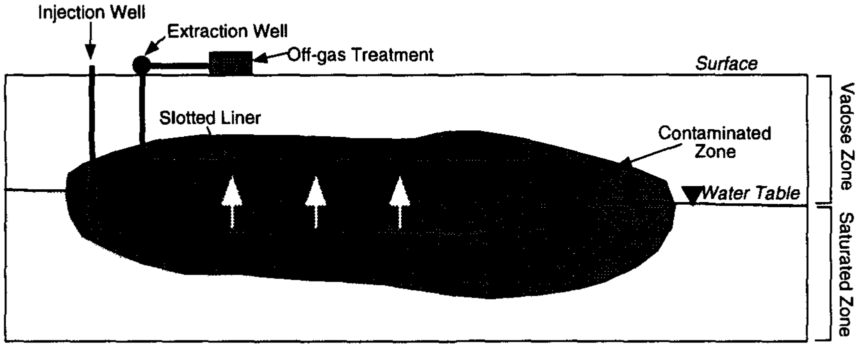
1

Technology Description

In Situ Air Stripping (ISAS) technology was developed to remediate soils and ground water contaminated with volatile organic compounds (VOCs) both above and below the water table. ISAS employs horizontal wells to inject (sparge) air into the ground water and vacuum extract VOCs from vadose zone soils. The innovation is creation of a system that combines two somewhat innovative technologies, air sparging and horizontal wells, with a baseline technology, soil vapor extraction, to produce a more efficient in situ remediation system.

- The horizontal wells provide a more effective access to the subsurface contamination
- The air sparging process eliminates the need for surface ground water treatment systems and treats the subsurface in situ, directly attacking the problem of subsurface contaminant retention.

The types of sites most likely to apply ISAS will contain permeable, relatively homogeneous sediments contaminated with VOCs.



(figure modified from Reference 6)

Technology Status

A full-scale demonstration was conducted as part of the Savannah River Integrated Demonstration VOCs in Nonarid Soils and Ground Water at:
U.S. Department of Energy
Savannah River Site
M Area Process Sewer/Integrated Demonstration Site
Aiken, South Carolina
July to December 1990

The demonstration site was located at one of the source areas within the one-square mile VOC ground water plume. Prior to application of ISAS, 1,1,2-trichloroethylene (TCE) and tetrachloroethylene (PCE) concentrations in ground water ranged from 500 to 1800 ug/L and 85 to 184 ug/L, respectively. TCE and PCE concentrations in sediments ranged from 1.26 to 16.32 mg/kg and 0.03 to 8.75 mg/kg, respectively. The site is underlain by a thick section of relatively permeable sands with thin lenses of clayey sediments. Appendix A describes the site in detail.

Key results included:

- Removal of nearly 16,000 lbs VOCs over a 139-day period. The daily removal rate from the upper horizontal well was equal to the eleven-well pump and treat system operating to contain the central portion of the plume that surrounds the demonstration site.
- Final TCE and PCE concentrations in ground water ranging from 10 to 1031 ug/L and 3 to 124 ug/L respectively. Final concentrations in sediments ranged from 0.67 to 6.29 mg/kg and 0.44 to 1.05 mg/kg, respectively.
- Completion of a cost-benefit analysis performed by Los Alamos National Laboratory showed that ISAS could reduce costs 40% over a baseline pump-and-treat/soil vapor extraction system.

The ISAS process is patented by the Department of Energy and has been licensed to eight commercial vendors with eleven additional license applications under review. Licenses are available through the Westinghouse Savannah River Company (WSRC). ISAS has been implemented at commercial sites in Minnesota, Missouri, North Carolina and New York. Many other sites plan to implement the technology in the next year.

Contacts

Technical

Brian Looney, Principal Investigator, Westinghouse Savannah River Company (WSRC), (803) 725-3692

Carol A. Eddy Dilek, Characterization, WSRC, (803) 725-2418

Dawn Kaback, Horizontal Drilling, Colorado Center for Environmental Management, (303) 297-0180, ext. 111

Management

Kurt Gerdes, DOE EM-50, DOE Integrated Demonstration Program Manager, (301)903-7289

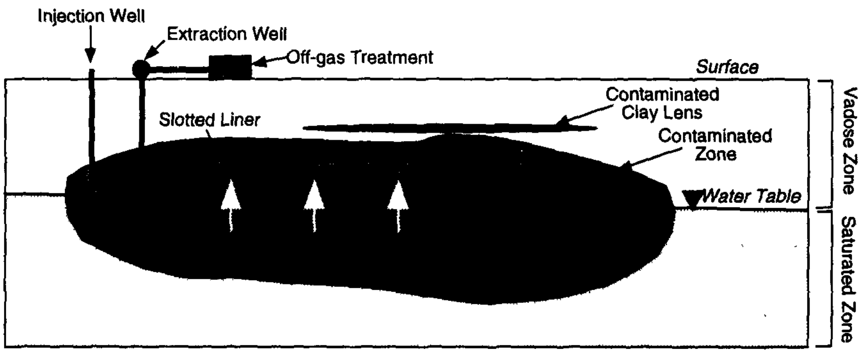
Jim Wright, DOE Plumes Focus Area Implementation Team Manager, (803) 725-5608

Licensing Information

Caroline Teelon, Technology Transfer Office, WSRC, (803) 725-5540

Overall Process Schematic

- Air injected through lower horizontal well, below the water table.
- Air/contaminant mixture extracted from upper horizontal well, above water table.
- Off-gas treatment available for long-term remedial operation, but not used for the demonstration described.

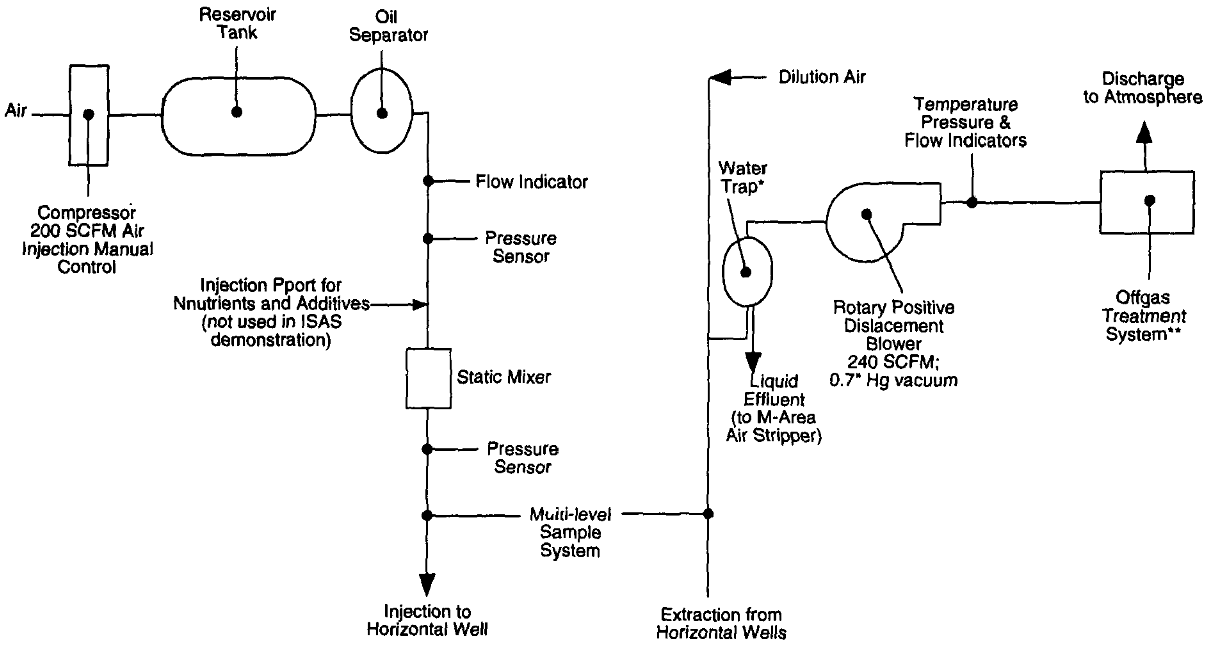


(figure modified from Reference 6)

Appendix B provides detailed information about the horizontal well installations and the monitoring wells installed.

Aboveground Systems

Air Injection ***Extraction & Offgas Treatment***



Notes:

* Water trap removes debris and moisture from airstream. System includes a daytank to drain water from separator for ultimate treatment at M-Area air stripper.

** Demonstration released VOCs directly to the atmosphere. Offgas treatment may be required for long-term remediation.

SECTION 3

PERFORMANCE

Demonstration Plan

Performance of the technology has been assessed using information from the full-scale demonstration at SRS. Major elements of the demonstration included:

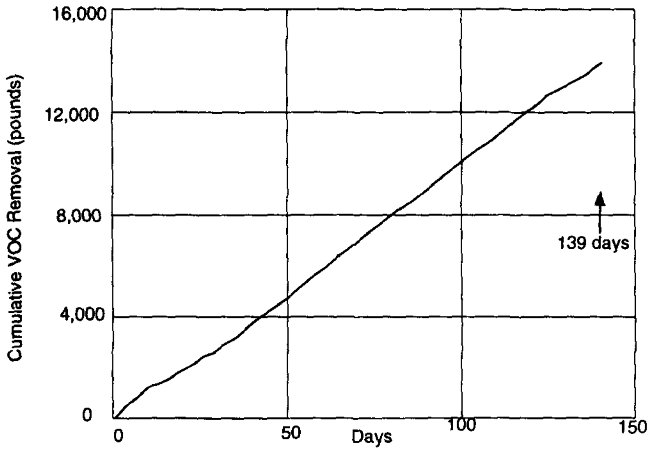
- initial vacuum extraction of vadose zone gases;
- addition of air sparging (simultaneous air injection into the saturated zone and extraction from the vadose zone) at low, medium, and high air injection rates;
- evaluation of temperature effects through heating of injected air;
- assessment of subsurface microbial activity; and
- assessment of the behavior of injected air through a 24-hour inert tracer (helium) test.

Key system parameters are explained on page 6. Appendix C describes the demonstration schedule, sampling and analysis to support performance monitoring, and the overall A/M Area cleanup program.

Treatment Performance

3

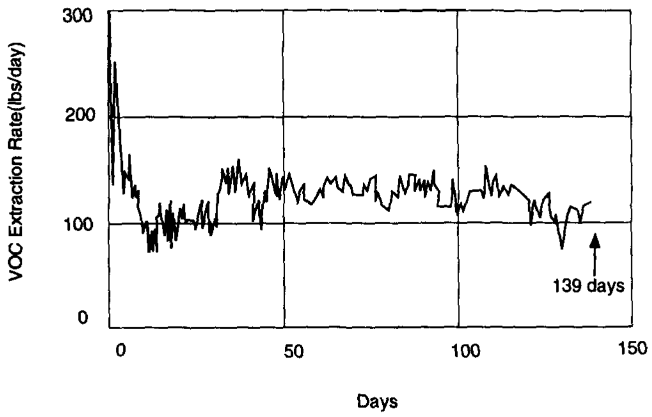
Amount of VOCs Removed



- Nearly 16,000 lbs of VOCs removed during the 139-day demonstration.
- Soil vapor extraction (without air injection) removed contaminants at a rate of 109 lbs/day.
- Combined injection and extraction increased the removal rate to 130 lbs/day.

(figure modified from Reference 11)

In Situ Air Stripping VOC Extraction Rates

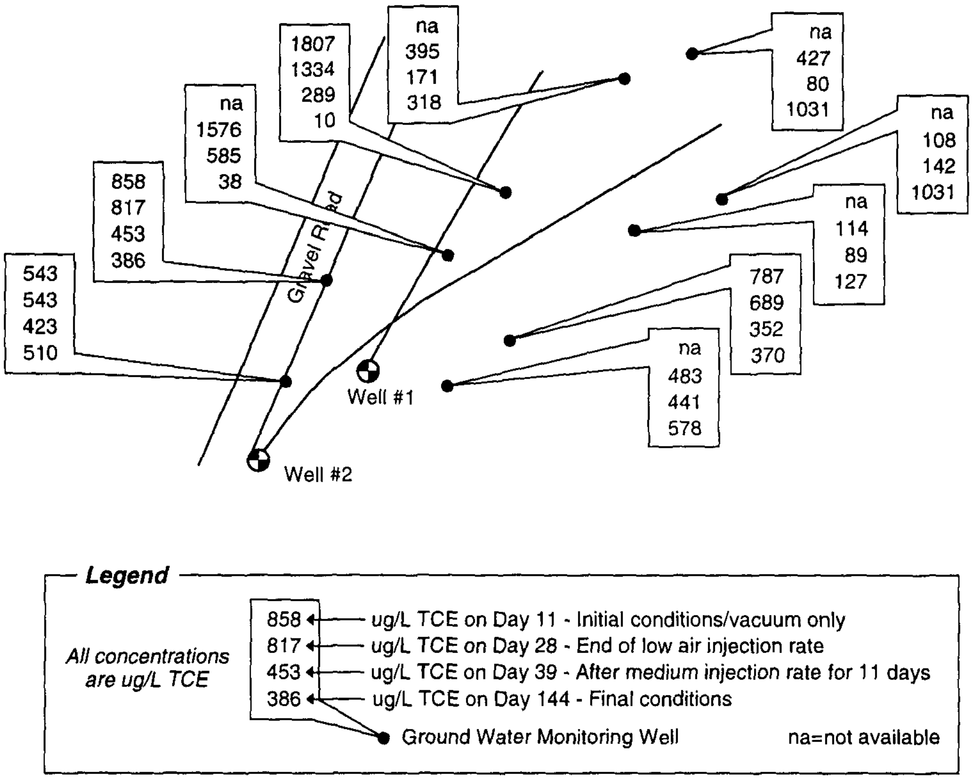


- Contaminant removal rate ranged between 100 and 140 lbs/day over most of the 139 days.
- Vacuum extraction removed an estimated 109 lbs/day (day s 1-16 and 113-139) while air injection removed an additional 20 lbs/day (days 16-113).

(figure modified from Reference 11)

Treatment Performance (continued)

Pre- and Post-Demonstration Ground Water Data: TCE Concentrations



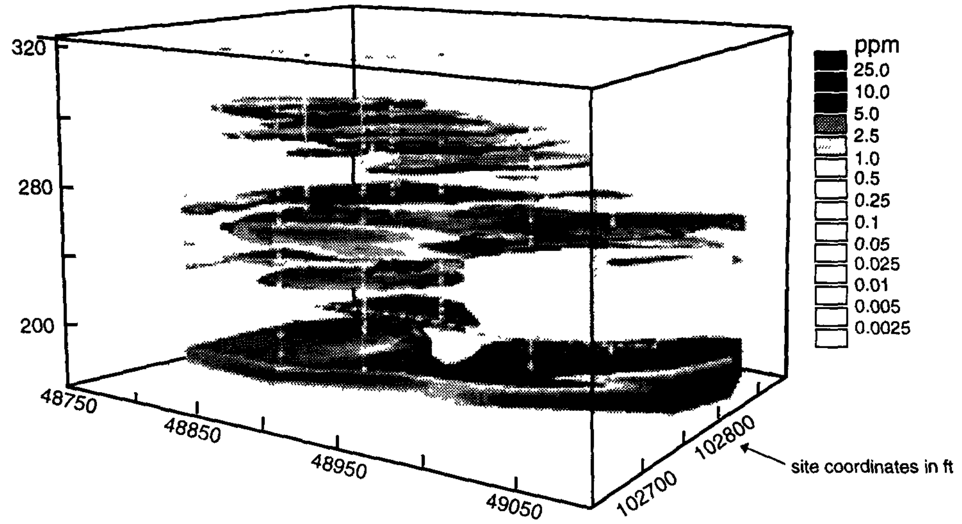
- Similar reductions in PCE concentrations were observed: initial concentrations of 85 mg/L to 184 mg/L were lowered to 3 mg/L to 124 mg/L.

- Two hypotheses are being examined to explain increases in VOC concentrations near the far ends of the horizontal wells:
  1) upward migration of contaminants caused by the injection of air below the monitoring well screen, and
  2) slight pressurization of the vadose zone between the water table and a zone of clays resulting in downward migration from the water table to the depth of the screen being measured.

Treatment Performance (continued)

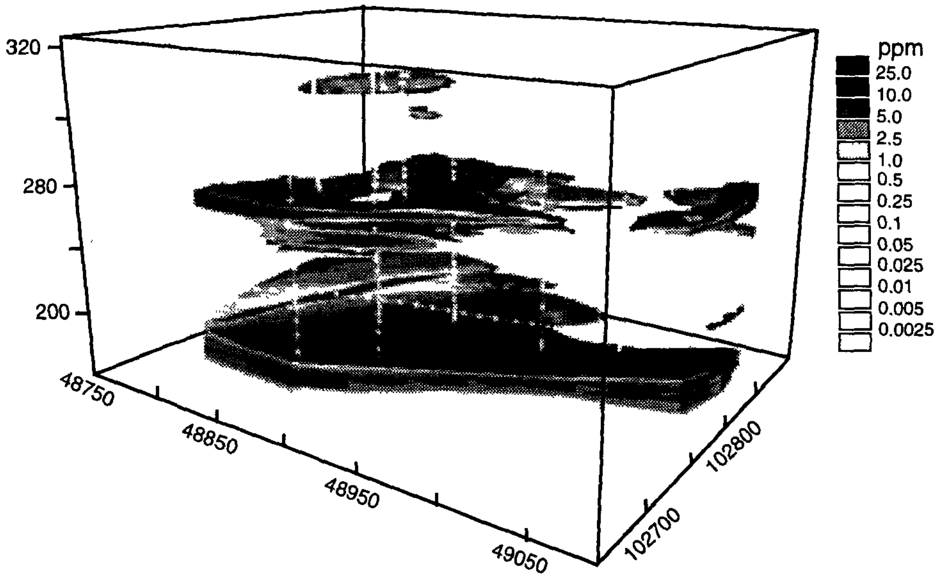
Pre- and Post-Demonstration Sediment Data

TCE concentrations in sediments before ISAS



The sediment data are known to underestimate the VOCs at the demonstration site, but can be used to develop a sense of relative amounts of contamination removed during the demonstration.

TCE concentrations in sediments after ISAS



Comparison of the pretest and post-test results suggest that 57% of the solvents were removed from the modeled volume during the five-month long demonstration.

Key System Parameters

Vacuum Applied

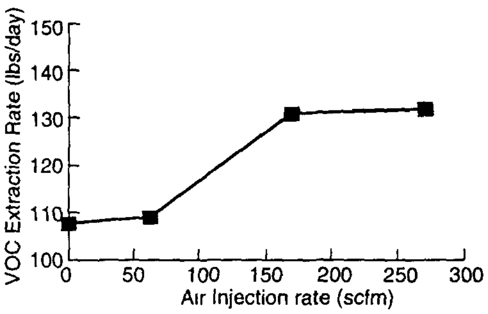
- Vacuum extraction from Well #2 in the vadose zone ranged from 550 to 600 scfm at 10 to 11 in of Hg.

Temperature Effects

- Heating of injected air up to 147°F had no measurable effect on system performance or on the temperature of extracted gas, which was relatively constant at 60°F.

Injection Pressure Effects

- Air injection was varied at low (65 scfm), medium (170 scfm), and high (270 scfm) rates during the demonstration.
- The effects of increasing injection pressure did not produce a linear increase in extracted VOCs as shown. Operating at lower flow rates may offer substantial cost savings without a major impact on performance.

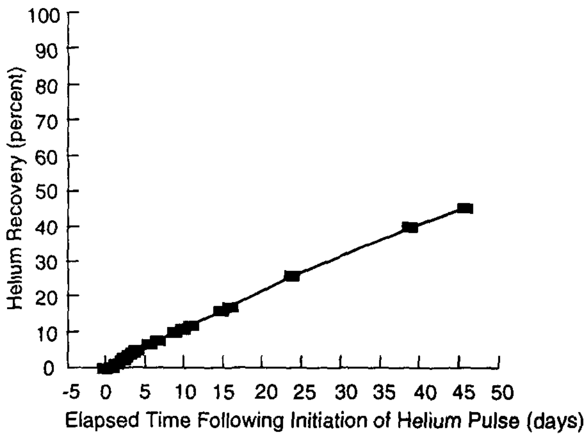


Microbial Activity

- Air injection significantly increased the biomass of microbes and their metabolic activity (2 to 3 orders of magnitude), especially at those wells where the greatest stripping effect was seen.
- Post-demonstration sediment data indicate that almost all contaminants in sediment in the vadose zone were removed primarily by microbial activity during later phases of demontration.

Results of Helium Tracer Test

- Helium was injected into the saturated zone horizontal well (Well #1) over a 24-hour period to determine:
  - the extent injected air was reaching extraction wells and
  - the extent injected air was escaping through monitoring wells.
- Results confirmed significant "communication" between injection and extraction wells with approximately 45% of injected helium recovered over nearly a 7-week period as shown at right. Injected air appeared to disperse throughout subsurface heterogeneities
- Losses through monitoring wells were estimated at less than 5% of the total injected air flow.



Zones of Influence

- The vacuum well in the vadose zone created a zone of influence estimated at greater than 200 ft based upon pressure measurements.
- Electrical resistance tomography (ERT), electromagnetic tomography (EMT) and seismic tomography were used to map a sparge zone of influence in the saturated zone approximately 40 to 60 ft wide (20 to 30 ft on either side of Well #1).

SECTION 4

TECHNOLOGY APPLICABILITY & ALTERNATIVES

Technology Applicability

• ISAS has been demonstrated to remediate soils, sediments and groundwater contaminated with VOCs both above and below the water table.

• The geometry of horizontal well treatment conforms to typical subsurface contaminated zones, which are often relatively thin but laterally extensive areas.

• Quantitative modeling and bench- and pilot-scale work indicate that ISAS would be effective at removing light nonaqueous phase liquids (LNAPLs). It is not suitable for dense nonaqueous phase liquids (DNAPLs).

• ISAS is not well suited for sites with highly stratified soils with low permeability layers, fractured rock or clay geologies. ISAS does not effectively remediate large dilute plumes but would be useful near source areas.

• Similar to pump-and-treat, ISAS may not be able to reach drinking water standards (without enhancements such as addition of nutrients to promote biodegradation).

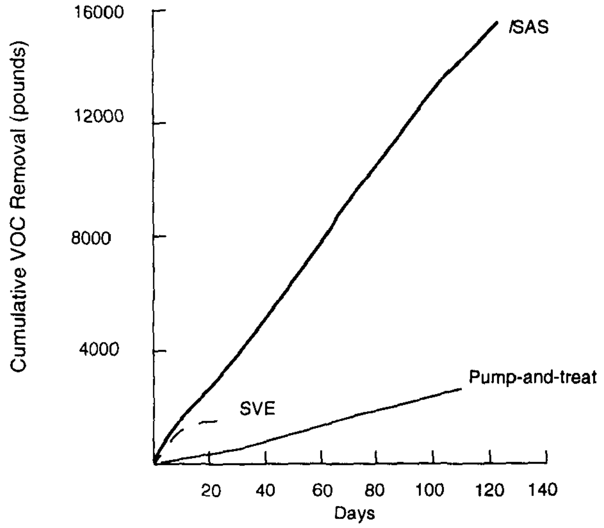
• Commercialization and intellectual property information is included in Appendix D.

Competing Technologies

• ISAS competes with conventional baseline technologies of pump-and-treat and pump-and-treat combined with soil vapor extraction (SVE). Numerous other thermal, physical/chemical, and biological technologies are also either available or under development to treat VOC-contaminated soils and ground water either in situ or aboveground.

• The effectiveness of ISAS was compared with performance data from application of pump-and-treat and SVE at SRS (Reference 9) as shown as right. Extrapolation of these data was the basis of the Los Alamos cost analysis discussed in Section 5.

• Vertical well air sparging and in well recirculation technologies have been implemented at a number of sites across the US and Europe.



Technology Maturity

• Air sparging with vertical wells is a relatively established technology offered by dozens of vendors. Variations of the technique have been implemented at hundreds of sites.

• ISAS using horizontal wells is currently being applied at an airport in New York and at industrial sites in North Carolina, Minnesota, and Missouri. The technology is also being implemented full-scale at SRS at two locations.

• A market survey on horizontal environmental wells was completed in 1993 (Reference 7). Key results of that study included:

- Since 1987, over one hundred horizontal environmental wells have been installed in the U.S.
- 25% have been used for ground water extraction, 25% for soil vapor extraction, and 50% for other purposes, including air injection, bioventing, and petroleum recovery.
- 80% of the horizontal wells have been installed at vertical depths of 25 ft or less.
- The rate of horizontal well installations has increased significantly in the last 2 years possibly because of more widespread recognition of advantages and improvements in drilling techniques, which have made installation more cost effective. A cursory update of the 1993 survey has shown that between July 1993 and December 1994 more than fifty horizontal environmental wells were installed.

SECTION 5

COST

Introduction

A cost study (Reference 9) was conducted by researchers from Los Alamos National Laboratory that compared in situ air stripping with horizontal wells against the conventional cleanup technologies of combined pump and treat and soil vapor extraction. Detailed capital and operating costs taken from the study for the ISAS application are presented below. Cost breakdown analyses and comparative assessments of ISAS cost versus those of conventional technologies are included in the sections that follow. Critical assumptions relevant to the quality of the cost data are included within each section.

Capital and Operating Costs

The Los Alamos study presented these costs as representative of the actual costs of demonstration (with the exception of offgas treatment as indicated below under "Notes"):

Equipment Costs	
Design and engineering (100 hrs @ $50/hr)	$5,000
Mobile Equipment (pickup truck)	15,000
Capital : Well installation (subcontracted)	
Air injection well (165 ft deep, 300 ft long)	93,323
Air extraction well (75 ft deep, 175 ft long)	76,762
Subtotal: Well installation	170,085
Other Equipment	
Air injection system (300 cfm blower)	3,500
Air extraction system (600 cfm blower)	5,000
Vapor air separator (1 @600 cfm)	2,750
Carbon adsorption unit (2@600 cfm canister)	10,000
Duct heater (2,000 btu propane fired)	3,250
Water treatment unit (12 gph recirculation unit)	4,000
Monitoring equipment	17,000
Temporary storage (metal shed)	1,500
Portable generator (25 kva)	3,500
Fuel storage (fuel oil and propane)	1,500
Piping and installation (10% of equipment cost)	5,200
Electrical (12% of equipment cost)	6,240
Subtotal: Other Equipment	63,440
Total Equipment Costs	**$253,525**

Site Costs	
Site Costs (set up and level area)	$5,000
Total Site Costs	**$5,000**
Labor Cost	
Mobilize/demobilize (based on 200 hrs set up & tear down)	
Technician --2	12,000
Laborers --2	10,000
Oversight engineer --1	12,000
Per diem	3,600
Monitoring/maintenance crew (139 days @ 2 hrs/day)	
Technician -- 1	8,340
Oversight engineer --1	16,680
Total Annual Labor Costs	**$62,620**
Consumable Costs	
Carbon recharge (2.23 lb carbon/lb VOC)	101,688
Fuel oil - diesel @ 10 gph	35,362
Lubricants	6,950
Deionized water	3,336
Chemical additives	6,950
Maintenance supplies	3,475
Total Annual Consumable Costs	**$157,761**

Notes:

1. Consumable supplies: Recycled carbon, $2.85/lb.; Diesel fuel, $1.06/gal; Lubricants, $50/day; Deionized water, $0.10/gal; Chemical additives, $50/day; Maintenance supplies, $25/day.

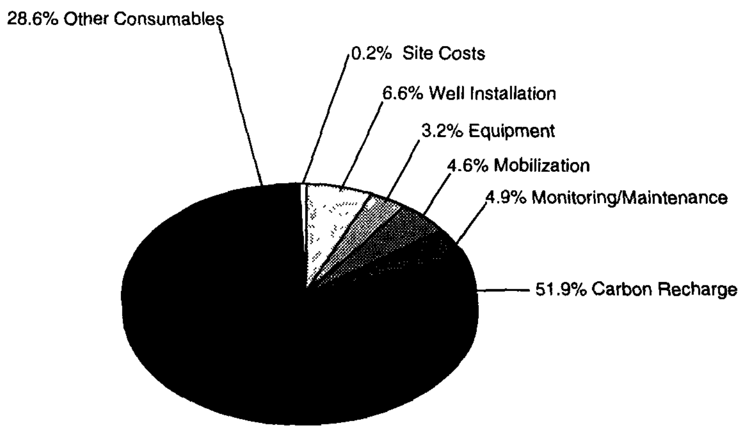
2. Offgas treatment costs assume conventional carbon adsorption. Demonstration did not include offgas treatment.

Cost Breakdown Analysis

- The Los Alamos study developed a breakdown of ISAS costs per pound of VOC removed during the 139 day demonstration period by annualizing capital costs over an estimated 10-year equipment life. Carbon adsorption was included for offgas treatment. However, more cost-effective offgas treatment systems might be applicable and could reduce annual costs substantially.

Cost/Lb of VOC Removed

Equipment	$1.51
Site	$0.31
Labor	$3.91
Consumables	$9.86
Total	$15.59



Cost Considerations for Future Applications

Cost Sensitivities

- Horizontal well installation costs are quite variable, depending upon depth of installation, site geology, site specific institutional requirements, well design, well materials, etc.
  - At depths greater than 40 to 50 ft, river crossing techniques are normally used at costs of approximately $200/ft.
  - At depths less than 40 to 50 ft, the utility industry compaction or smaller river crossing rigs can be used at costs as low as $50/ft.
- Horizontal well installation costs have steadily decreased in recent years due to technical improvements and increased experience of drilling companies.

Horizontal Well Costs Versus Vertical Well Costs

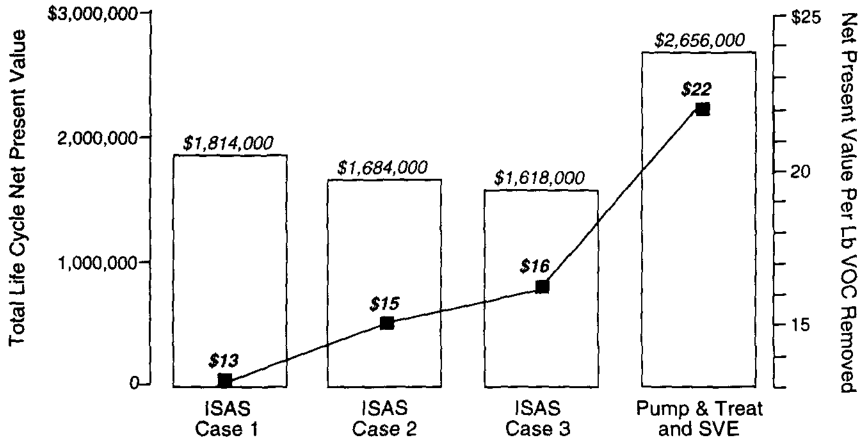
- Promotional literature from horizontal well service providers show that, depending upon plume geometry and site characteristics, one horizontal well can replace five to fifty vertical wells. One hypothetical project cost comparison (Reference 5) illustrated that one horizontal well could accomplish the same containment/remediation objectives as ten vertical wells at a cost savings of nearly 80%. The higher individual capital cost of a horizontal well was offset in this case by the large number of vertical wells replaced and their larger associated costs for surface equipment, operations and maintenance.

- A horizontal well case study at a Department of Defense site predicted one horizontal well to replace 80 vertical wells.

Cost Considerations for Future Applications (continued)

Cost Savings Versus Alternative Technologies

The Los Alamos study evaluated the demonstrated cost of ISAS versus the combined cost of pump-and-treat with soil vapor extraction. The cost and removal rates of the ISAS system were extrapolated from data from the demonstration and compared to data from the in place baseline technology at SRS. All systems were normalized to remediate equivalent zones of contamination. ISAS Cases 1, 2 and 3 represent different assumed VOC extraction rates over 5 years of operation. The VOC extraction rates assumed are detailed in the table at the bottom of the page. Costs over a 5 year life cycle were:



The costs above are based in part upon the following VOC removal data and assumptions. Unless noted, all values are in lbs of VOC extracted/day.

		ISAS Case 1	ISAS Case 2	ISAS Case 3	Pump-and-Treat and SVE	
Actual VOC Removal Data*		← 16,000 lbs over 139 days →			Pump-and-Treat: 2700 lbs over 114 days	SVE: 7480 lbs over 21 days
Assumed Projected VOC Removal Data**	Year 1	115	86	57	23	80
	Year 2	86	57	57	17	60
	Year 3	57	57	57	11	40
	Year 4	57	57	57	11	40
	Year 5	57	57	57	11	40

* VOC extraction rates taken from the results of short-term application at SRS

** Projected VOC extraction rates for five years of operation. ISAS Cases 1, 2 and 3 represent increasingly conservative estimates of ISAS performance over longer periods.

SECTION 6
REGULATORY/POLICY REQUIREMENTS & ISSUES

Regulatory Considerations

• Permit requirements for the demonstration conducted in 1990 were controlled by the South Carolina Department of Health and Environmental Control (SCDHEC) and included an Air Quality Control (AQC) permit waiver and an Underground Injection Control (UIC) permit issued by the South Carolina Board of Drinking Water Protection.

• Permit requirements for future applications of ISAS are expected to include an air permit for discharge of treated vapor extracted from the subsurface. For applications in some states, underground injection permits may be required for air injection. Some federal projects may also require a National Environmental Policy Act (NEPA) review.

• Groundwater Protection Standards (GWPS) have been established as part of a RCRA permit for the M-Area. The GWPS' are based upon EPA Maximum Contaminant Levels (MCLs). Specific goals for contaminants of greater concern are:

Compound	Concentration [ppb]
TCE	5
PCE	5
TCA	200

• For application of ISAS as a remedial activity at the M-Area HWMF, the RCRA Part B Permit must be reviewed to determine if a permit modification is necessary. Offgas treatment is expected to be required for full-scale remediation at SRS.

• The ISAS system experienced no regulatory compliance problems during demonstration at SRS nor are any future regulatory changes anticipated to pose compliance obstacles. ISAS has been subsequently approved by regulators for use at additional sites both at SRS and in other states, including New York, Minnesota, Missouri, and North Carolina.

Safety, Risks, Benefits, & Community Reaction

Worker Safety

• Health and safety issues for the installation and operation of ISAS are essentially equivalent to those for conventional technologies of pump-and-treat or soil vapor extraction.

• Level D personnel protection was used during installation and operation of the ISAS system.

Community Safety

• ISAS with offgas treatment does not produce any routine release of contaminants.

• No unusual or significant safety concerns are associated with the transport of equipment, samples, waste, or other materials associated with ISAS.

Environmental Impacts

• ISAS systems require relatively little space, and use of directional drilling minimizes clearing and other activities that would be needed to install a comparable vertical well network.

• Visual impacts are minor, but operation of the vacuum blower and compressor create moderate noise in the immediate vicinity.

Socioeconomic Impacts and Community Perception

• ISAS has a minimal economic or labor force impact.

• The general public has limited familiarity with ISAS: however, the technology received positive support on public visitation days at Savannah River. ISAS can be explained to the public with ease similar to that of pump-and-treat technologies.

SECTION 7

LESSONS LEARNED

Design Issues

- The bundle-tube pressure sensors installed along horizontal wells 1 and 2 to measure injection/extraction efficiency are inexpensive and recommended for future applications.
- The filter pack on all the horizontal wells is made up of natural formation solids, principally because of collapse around the borehole. This may diminish well efficiencies. Well design must be tailored to the ultimate use of the well. Prepacked screen should only be used if necessary because it adds significantly to the cost.
- A horizontal well removes water from the vadose zone that can collect in the well, reducing its effective length. Wells must be designed to channel water away from low areas.
- Careful alignment of the injection and extraction wells is probably not necessary because the zone of influence of the extraction well is far greater than that of the injection well and because subsurface heterogeneities strongly influence air flow.
- The system must be designed carefully to minimize the potential for plume spreading during injection

Implementation Considerations

- Increasing injection flow rates did not result in linear increases in mass removal; operating at lower flow rates may save on operating costs with only a modest impact on performance.
- Cycling operations may offer substantial cost savings for only a marginal performance penalty.
- Air sparging efficiency is affected by injection pressure, flow rates, permeability, and subsurface heterogeneities.
- The injection of heated air is unlikely to result in increased VOC removal based upon the results of field tests.
- Horizontal drilling methods must be tailored to specific site conditions with special considerations for the type of drilling fluid, drilling bit, drilling methodology, casing installation, etc.

Technology Limitations/Needs for Future Development

- Clay layers, because of their low permeability, are troublesome. Heterogeneities in the subsurface, caused by either stratigraphy or fractures, can create preferential air flow pathways, resulting in less effective contact and remediation.
- By inducing water flow, ISAS can accelerate lateral migration of contaminants in certain geologic settings. If clay layers or other geologic features constrict vertical flow, it may be necessary to use ISAS in conjunction with a pump-and-treat system for hydraulic control.
- Long-term performance data from several years of operation are required to assess the need for design improvements and to better quantify life-cycle costs.
- Simplified design and monitoring methods are required to facilitate implementation of ISAS.
- Determination of the most effective enhancements to the technology, such as addition of nutrients to promote biodegradation, presents opportunities to significantly improve performance. Follow-on work, not discussed in this analysis, involving methane injection to bioremediate the site has already produced positive results.
- More experience with environmental horizontal drilling under a variety of subsurface conditions will ensure better well installations at reduced costs.

Technology Selection Considerations

• Directional drilling of horizontal wells was demonstrated to assess its role in improving the efficiency of a remediation project. Remediation efficiency may be enhanced by increased surface area for reaction, similarity of well profile and contaminant plume geometry, borehole access to areas beneath existing facilities, and drilling along facility boundaries to control plume migration. However, each site must be assessed for the utility of horizontal wells.

• Successful ISAS requires good contact between injected air and contaminated soils and ground water. An optimal geologic setting would have moderate to high saturated soil permeability, a homogenous saturated zone, and sufficient saturated thickness. Vadose zone characteristics would be high permeability and homogeneity. Air stripping is more effective in coarse-grained soil.

• For ISAS to be effective, the contaminants of concern must be strippable, that is mobile in and between all phases. Most light hydrocarbons and chlorinated solvents satisfy these conditions.

• Horizontal wells may provide for better contact with linearly shaped plumes. ISAS may be more effective with relatively thin plumes of contaminants.

APPENDIX A

DEMONSTRATION SITE CHARACTERISTICS

A

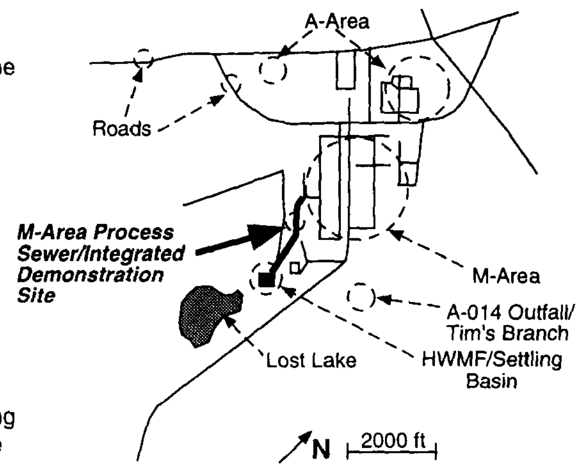
Site History/Background

- The Savannah River Site's historical mission has been to support national defense efforts through the production of nuclear materials. Production and associated research activities have resulted in the generation of hazardous waste by-products now managed as 266 waste management units located throughout the 300 mile^2 facility.

- The A and M Areas at Savannah River have been the site of administrative buildings and manufacturing operations, respectively. The A/M-Area is approximately one mile inward from the northeast boundary of the 300 mile^2 Savannah River Site. Adjacent to the site boundary are rural and farming communities. Specific manufacturing operations within the M-Area included aluminum forming and metal finishing.

- The M-Area operations resulted in the release of process wastewater containing an estimated 3.5 million lbs of solvents. From 1958 to 1985, 2.2 million lbs were sent to an unlined settling basin, which is the main feature of the M-Area Hazardous Waste Management Facility (HWMF). The remaining 1.3 million pounds were discharged from Outfall A-014 to Tim's Branch, a nearby stream, primarily during the years 1954 to 1982.

Site Layout



- Discovery of contamination adjacent to the settling basin in 1981 initiated a site assessment effort eventually involving approximately 250 monitoring wells over a broad area. A pilot ground water remediation system began operation in February 1983. Full-scale ground water treatment began in September 1985.

- High levels of residual solvent are found in the soil and ground water near the original discharge locations. Technologies to augment the pump-and-treat efforts, for example soil vapor extraction, ISAS, and bioremediation, have been tested and are being added to the permitted corrective action.

Contaminants of Concern

Contaminants of greatest concern are:

1,1,2-trichloroethylene (TCE)
tetrachloroethylene (PCE)
1,1,1-trichloroethane (TCA)

Property at STP*	Units	TCE	PCE	TCA
Empirical Formula	-	$ClCH{=}CCl_2$	$Cl_2C{=}CCl_2$	CH_3CCl_3
Density	g/cm^3	1.46	1 62	1 31
Vapor Pressure	mmHg	73	19	124
Henry's Law Constant	atm*m^3/mole	9.9E-3	2.9E-3	1.6E-2
Water Solubility	mg/L	1000-1470	150-485	300-1334
Octanol-Water Partition Coefficient; K_{OW}	-	195	126	148

**STP = Standard Temperature and Pressure; 1 atm, 25 ^oC*

Nature and Extent of Contamination

- Approximately 71% of the total mass of VOCs released to both the settling basin and Tim's Branch was PCE, 28% was TCE, and 1% was TCA.

- The estimated amount of dissolved organic solvents in ground water in concentrations greater than 10 ppb is between 260,000 and 450,000 lbs and is estimated to be 75% TCE. This estimate does not include contaminants sorbed to solids in the saturated zone or in the vadose zone. The area of VOC-contaminated ground water has an approximate thickness of 150 feet, covers about 1200 acres, and contains contaminant concentrations greater than 50,000 ug/L.

- DNAPLs found in 1991 present challenges for long-term remediation efforts.

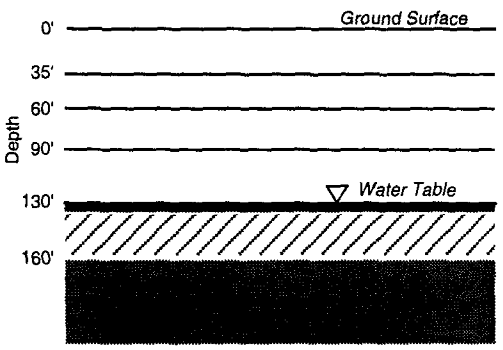
- Vadose zone contamination is mainly limited to a linear zone associated with the leaking process sewer line, solvent storage tank area, settling basin, and the A-014 outfall at Tim's Branch.

A

Contaminant Locations and Hydrogeologic Profiles

Simplified schematic diagrams show general hydrologic features of the A/M Area at SRS.

Vadose Zone and Upper Aquifer Characteristics



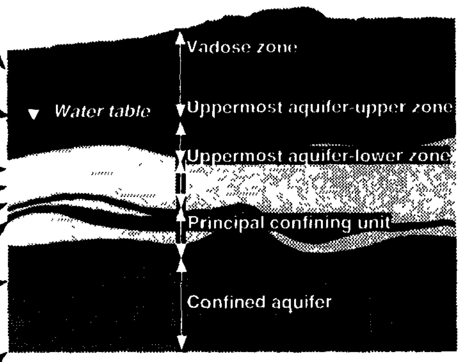
(figure modified from Reference 12)

Legend
- Water Table
- Unsaturated Zone
- Semiconfined Aquifer
- Confined Aquifer

- Sediments are composed of sand, clay and gravel.
- Clay layers are relatively thin and discontinuous, with the exception of the clay layers at 160-foot depth and a thicker zone of interbedded clay and sand found at 90-foot depth.
- The water table is approximately 135 feet below grade.
- A moderate downward gradient appears to exist beneath the M-Area. Vertical flow rates have been estimated to be 2 to 8 ft/year.
- Radial flow outward from a groundwater plateau under most of the A/M-Area exists. Flow is approximately 15 to 100 ft/year.

Hydrogeologic Units

Aquifer Unit	Description	Thickness
Vadose Zone	Poorly sorted mix of sand, cobbles, silt and clay	~57 ft
	Moderate to well-sorted, fine to medium sand containing some pebbles; 13% silt and clay	0-97 ft
	Moderately to well-sorted medium sand; 18% silt and clay	30-55 ft
Water Table Unit	Moderate to well-sorted fine sand with some calcaneous zones; 25% silt and clay; 14% silt and clay beds	16-34 ft
Lost Lake Aquifer — Upper	Well-sorted fine to medium sand; 16% silt and clay; 7% silt and clay beds.	14-60 ft
Lost Lake Aquifer	*Discontinuous clay beds containing 70% silt & clay*	
Lost Lake Aquifer — Lower	Moderate to well-sorted medium sand; 17% silt and clay, 7% silt and clay beds	4-44 ft
Crouch Branch Confining Unit	Clay, clayey silt, and poorly sorted fine to coarse, clayey sand; 62% silt and clay; contains 2 major clay layers the lower of which is 10-56 ft thick and *is the principal confining unit for lower aquifer zones*	32-95 ft
Crouch Branch Aquifer	Very poorly to well-sorted, medium to coarse sands; 5% sand and clay beds; an important production zone for water supply wells in the M-Area	152-180 ft



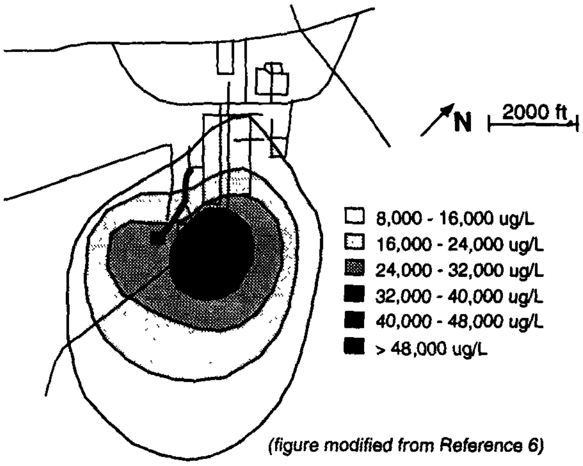
A

Contaminant Locations and Hydrogeologic Profiles (continued)

Metal-degreasing solvent wastes were sent to the A-014 outfall and, via the process sewer, to the M-Area settling basin. Data from hundreds of soil borings, ground water monitoring wells, and a variety of other investigative techniques have established a well-documented VOC plume in both the vadose and saturated zones.

TCE Ground Water Plume (Top View)

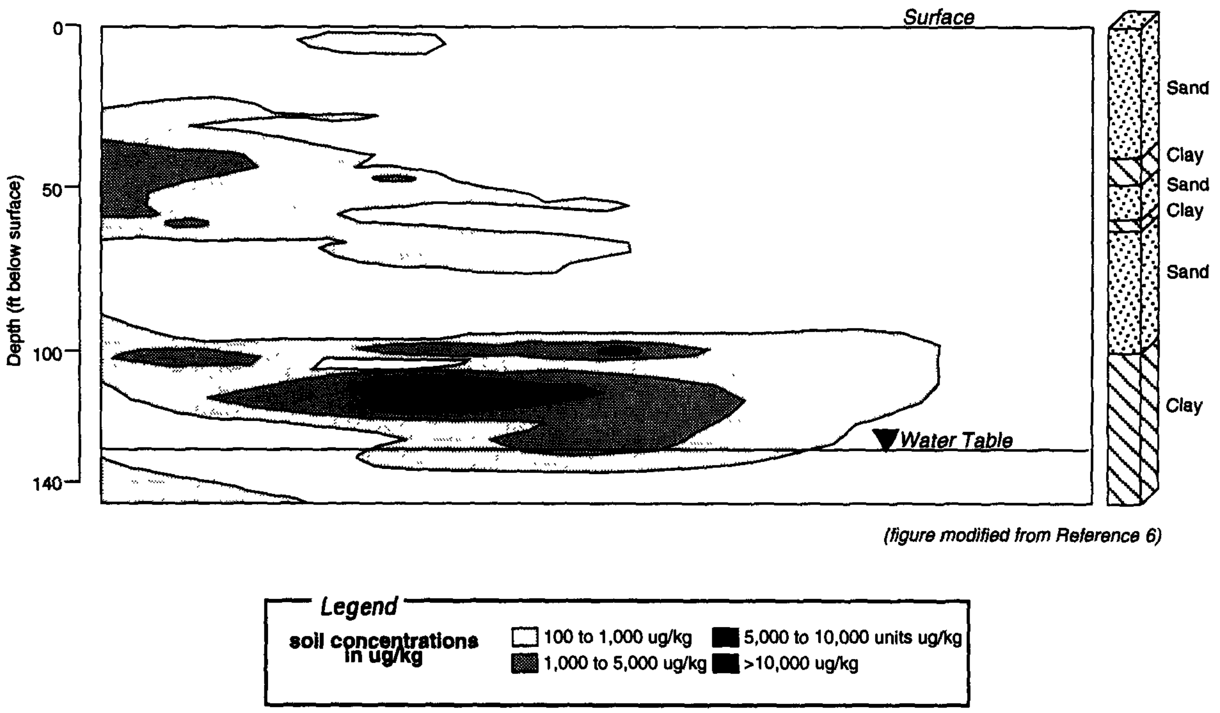
Data from 15 feet below water table in the third quarter of 1990.



(figure modified from Reference 6)

TCE Concentrations in Soil (West-East Cross-Section)

Concentration and lithology data from 1991 along an approximately 200-ft cross-section across the integrated demonstration site. Concentration contours of TCE in sediments are based on analysis of over 1000 sediment samples. Highest concentrations of TCE occur in clay zones.



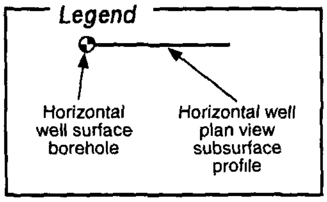
(figure modified from Reference 6)

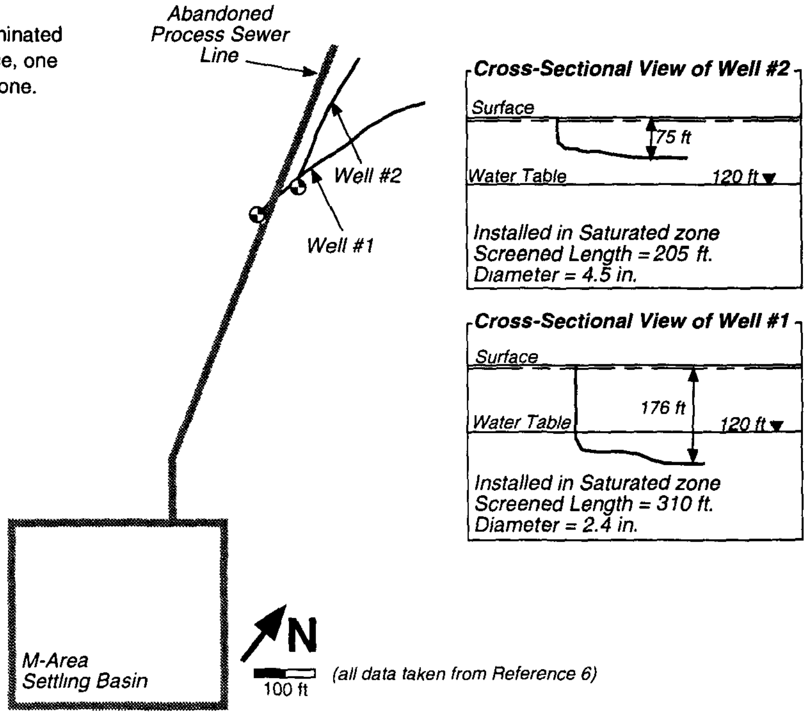
APPENDIX B

TECHNOLOGY DESCRIPTION DETAIL

System Configuration

- Wells 1&2 are paired wells targeting contaminated sands. They are semiparallel in the subsurface, one in the vadose zone and one in the saturated zone.

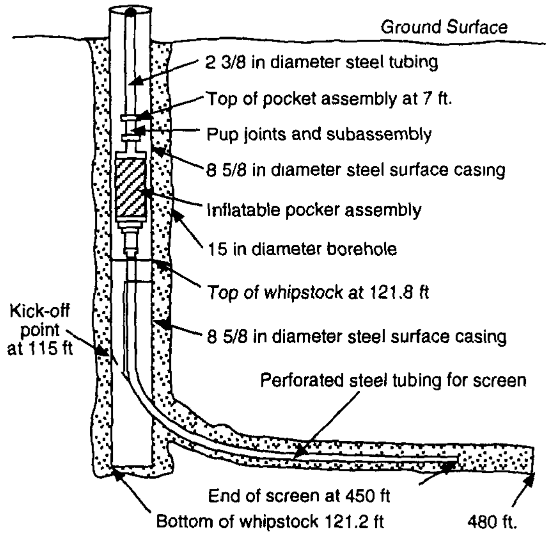




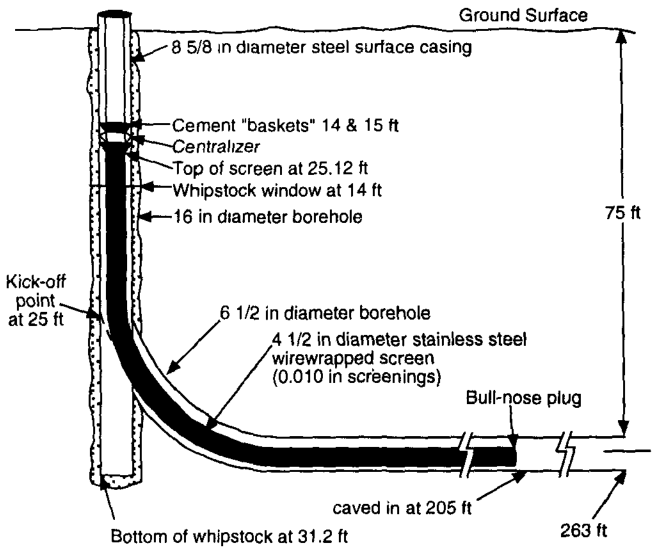
(all data taken from Reference 6)

Horizontal Well Close-Ups

Well # 1



Well # 2



Horizontal Well Installation Techniques

The techniques used to directionally drill and install a horizontal well depend on the location and purpose of the well. Petroleum industry technology was used to install wells 1 and 2 at the Savannah River Site; however, this technology is no longer used. Current installation techniques include the following:

1. **Pipeline/Utility River Crossing System**- Based on a mud rotary system used to drive a downhole drill assembly, including a drilling tool, a hydraulic spud jet with a 2-degree bend to provide directional drilling or a downhole motor depending on the lithology to be drilled.

2. **Utility Industry Compaction System** -Down hole drill assembly consists of a wedge-shaped drilling tool and a flexible subassembly attached to the drill string. The borehole is advanced by compaction, forcing cuttings into the borehole wall. Reduced volumes of water are introduced to cool the drill bit; no cirdulation of drilling flulid is accomplished.

3. **Hybrid Petroleum Industry/Utility Industry Technology** - Modified mud rotary system with bottom hole assembly comprised of a survey tool, steerable downhole motor, and expandable-wing drill bit. Drilling fluids are used. Curve is drilled and pipe is installed in curve before horizontal is drilled. Only one company provides this type of drilling system.

Operational Requirements

- Design and management of ISAS systems require expertise in environmental, chemical, mechanical, and civil engineering as well as hydrogeology and environmental regulations. Operation of multiple systems of the scale implemented at the Savannah River Site can be performed by a 1/3 full-time equivalent technician. Larger systems or extensive monitoring activities would require additional staff.

Monitoring Systems

Ground Water Monitoring Well Clusters

- Ten boringswere completed as 4-in monitoring well clusters in the locations shown on the following page.
- One well from each cluster was screened in the water table at elevations ranging from 216 to 244 ft.
- The second well in the cluster was screened in the underlying semiconfined aquifer at elevations ranging from 204 to 214 ft.

Vadose Zone Piezometer Clusters

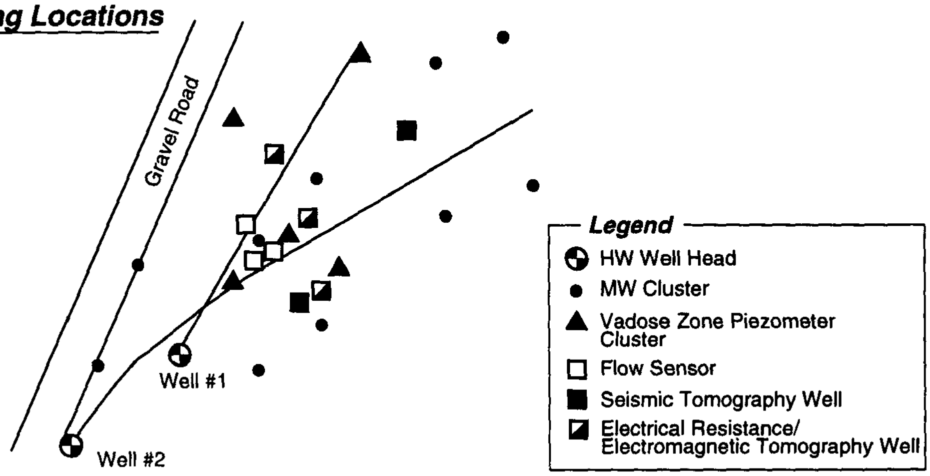
- Five borings were cored in order to install piezometer clusters in the vadose zone.
- Three piezometer tubes having lengths of approximately 52 ft, 77 ft and 100 ft were installed into each borehole.

Geophysical Monitoring

- Eight borings were completed for geophysical monitoring.
- Seismic tomography was performed in two borings. This technique was used to map subsurface structure and to monitor the extent of the air-stripping process.
- ERT and EMT were performed in three borings. ERT and EMT map the behavior of subsurface fluids as they change in response to natural or remedial processes.
- Several single-point flow sensors were placed between the injection and extraction wells (just below the water table) to measure ground water flow in the area most affected by the ISAS process.

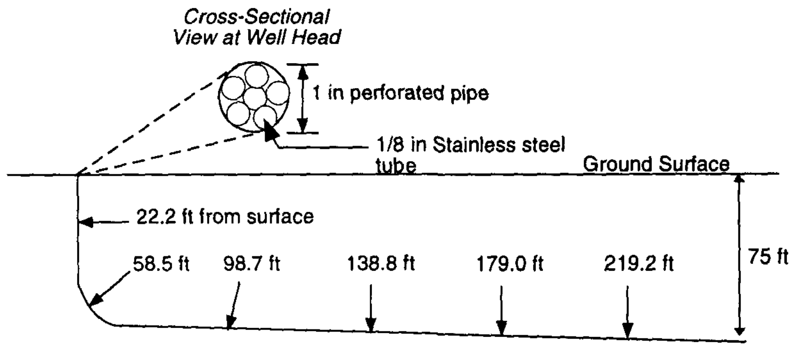
Monitoring Systems (continued)

Sampling/Monitoring Locations



Bundle Tubes

Each horizontal well was filled with a bundle of six tubes encased in a perforated pipe or well screen. Each tube terminated at a discrete distance from the surface for sampling or monitoring at different locations along the well bore.



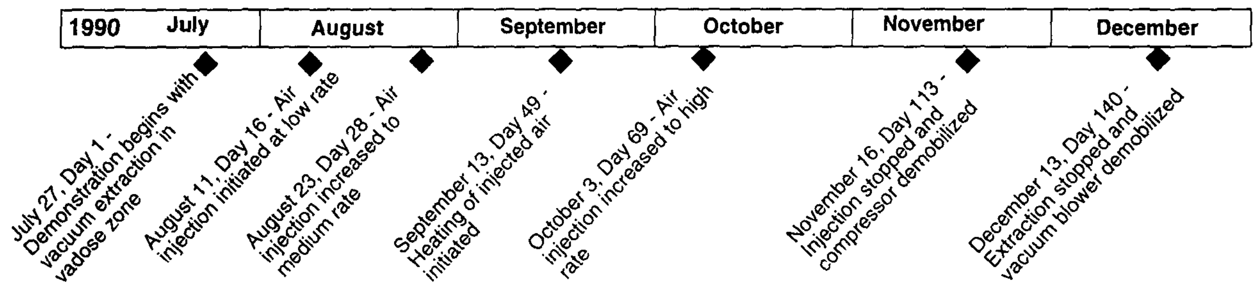
PERFORMANCE DETAIL

Operational Performance

Maintainability and Reliability	Operational Simplicity
• No functional problems encountered during demonstration; system was operational approximately 90% of all available time. • Operational performance over long periods (years) not yet available.	• Monitoring performance of ISAS is more difficult than monitoring performance of baseline pump-and-treat technology; however, systems can be operated and maintained in the field typically by less than 1 full-time equivalent technician. Staffing requirements are detailed in Appendix B.

Demonstration Schedule

Major Milestones of the Demonstration Program



Sampling, Monitoring, Analysis, and QA/QC Issues

Objectives

- Gather baseline information and fully characterize site
- Evaluate removal efficiencies with time
- Identify and evaluate zones of influence

Baseline Characterization

- Baseline characterization was performed before the demonstration to gather information on the geology, geochemistry, hydrology, and microbiology of the site. The distribution of contaminants in soils and sediments in the unsaturated zone and ground water was emphasized. These data were compared with data on soil collected during and after the demonstration to evaluate the effectiveness of ISAS.
- Continuous cores were collected from monitoring well and vadose zone boreholes. Sediments for VOC analysis were collected at 5-ft intervals and at major lithology changes. Samples for microbiological characterization were collected every 10 ft.
- Water samples were collected and analyzed for VOC content and microbial characteristics from monitoring well clusters and at discrete depths adjacent to monitoring well clusters.
- Geologic cross-sections were prepared using gamma ray, sp, resistivity density, and neutron geophysical logs and core logs.

Sampling, Monitoring, Analysis and QA/QC Issues (continued)

Sampling & Monitoring

	Location(s)	Frequency	Technique
Pressure Monitoring	vadose zone piezometers	3 X daily	measured at surface using magnehelic or slack-tube macrometer
	injection well		measured at wellhead using pressure gauge
Vacuum Monitoring	extraction well	3 X daily	measured at wellhead using vacuum gauge
	extraction well bundle tubes	weekly	measured at surface
Temperature Monitoring	vadose zone piezometers	3 X daily	measured at surface using temperature gauge
	injection well	3 X daily	same as above
	extraction well	3 X daily	same as above
Vapor Sampling	vadose zone piezometers	weekly	sampled through a septum on the vacuum side of a vacuum pump using gas-tight syringes
	extraction well	3 X daily	same as above
	bundle tube	weekly	same as above
Ground Water Sampling	monitoring well clusters	weekly	sampled using documented Savannah River Site (SRS) well sampling protocols
Microbiological Sampling	monitoring well clusters	biweekly	sampled using documented SRS well sampling protocols
Helium Tracer Test	all exit points	once	sampled using 500-ml disposable syringes and transferred to 30-ml preevacuated serum vials

Analytical Methods and Equipment

- Vapor grab samples were analyzed in the field using both a Photo Vac field gas chromatograph (GC) and a GC fitted with flame ionization and electron capture detectors. Analysis was performed immediately after collection.
- Bulk water parameters, including temperature, pH, dissolved oxygen, conductivity, and oxidation reduction potential, were measured using a Hydrolab.
- VOC analysis of water and sediment samples was performed onsite using an improved quantitative headspace method developed by Westinghouse Savannah River Company. Analyses were performed on an HP-5890 GC fitted with an electron capture detector and headspace sampler.
- Helium tracer samples were analyzed using a helium mass spectrometer modified to sample serum vials at a constant rate.

QA/QC Issues

- Vapor samples were analyzed immediately after collection and GC analysis of soil and water samples were completed less than 3 weeks after collection.
- Duplicate analysis was performed for nearly every water and sediment sample collected.
- Approximately 161 samples were analyzed offsite using standard EPA methods to corroborate onsite testing which used the improved quantitative headspace method described earlier. Cross-comparison showed that the quantitative headspace analysis generated equivalent to superior data.
- GC calibration checks were run daily using samples spiked with standard solutions.

Performance Validation

- Samples analyzed onsite by nonstandard EPA methods were sent offsite for confirmatory analysis using EPA methods. Results from these analyses confirmed the findings of Savannah River efforts.
- The effectiveness of horizontal wells for environmental cleanup has been demonstrated by their use in vapor extraction and ground water/free product recovery systems which are also discussed in Appendix D.

C

APPENDIX D

COMMERCIALIZATION/INTELLECTUAL PROPERTY

Marketplace Opportunities

- A key competitive advantage of ISAS is the use of horizontal wells. Horizontal wells can be used to:
  - remediate beneath buildings and other obstacles to avoid interference with aboveground activities,
  - remediate linear sources of contamination such as beneath pipelines,
  - prevent further migration of contamination along site boundaries, and
  - provide improved access to the subsurface especially for remedial enhancement processes such as bioremediation.
- Additional advantages of ISAS/horizontal well technology include:
  - reduction in the numbers of wells required and their associated pumps and surface equipment, and
  - elimination of contaminated ground water as a secondary waste stream as a result of the in situ treatment.
- The success of the ISAS demonstration has led to plans for reimplementation at the same site as well as application at other locations at SRS.
- ISAS has a potential market at sites where conventional technologies have failed to produce acceptable results. An application at an airport in New York is one example where a pump-and-treat system had been previously applied.
- WSRC has received hundreds of inquiries from private industrial site owners (especially oil companies) as well as from consultants and regulators. This response has led to the creation of a WSRC Industrial Assistance Program. Specific activities of this program have included:
  - input to feasibility studies to determine potential applicability of ISAS,
  - aid in determining design criteria for surface and subsurface equipment,
  - technical assistance to equipment vendors and manufacturers, and
  - participation in the regulatory negotiating and permit approval process.

D

Intellectual Property

Primary Sponsor

U.S. Department of Energy, Office of Environmental Management, Office of Technology Development

Existing/Pending Patents

Several parties, including national laboratories, technology developers, and consultants, participated in the development and implementation of the ISAS system. These participants are listed on page 26.

- Patent 4,832,122, "In Situ Remediation System and Method for Contaminated Groundwater," J.C. Corey, B.B. Looney, and D.S. Kaback, assignors to the U.S. as represented by the U.S. DOE.
- Patent 5,186,255, "Flow Monitoring and Control System for Injection Wells," J.C. Corey, assignor to the U.S. as represented by the U.S. DOE.
- Patent 5,263.795, "In Situ Remediation System for Groundwater and Soils," J.C. Corey, D.S. Kaback, and B.B. Looney, assignors to the U.S. as represented by the U.S. DOE.

- Related patents include:
  - Patent 4,660,639, "Removal of Volatile Contaminants from the Vadose Zone of Contaminated Ground," M.J. Visser and J.D. Malot assignors to the Upjohn Company. WSRC paid a one-time license fee to the assignee for the use of the process with horizontal wells.
  - Patent 5,006,250, "Pulsing of Electron Donor and Electron Acceptor for Enhanced Biotransformation of Chemicals," P.V. Roberts, G.D. Hopkins, L. Semprini, P.L. McCarty, and D.M. McKay, assignors to the Board of Trustees of the Leland Stanford Junior University.

- There are no pending patents for ISAS.

Intellectual Property (continued)

Licensing Information

- ISAS is commercially available through the WSRC Technology Transfer Office
- To date, 19 licenses have been applied for and 8 licenses have been granted.

Collaborators

ISAS Demonstration Participants

CDM Federal Programs Corporation
Conoco, Inc.
Eastman Christensen Company
Environmental Monitoring and Testing
Graves Well Drilling
Los Alamos National Laboratory
Lawrence Berkeley Laboratory
Lawrence Livermore National Laboratory
Martin Marietta Energy Systems, Inc., HAZWRAP
Sandia National Laboratories
Sirrine Environmental
South Carolina Department of Health and Environmental Control
Terra Vac, Inc.
University of California at Berkeley
University of South Carolina
U.S. EPA

APPENDIX E
REFERENCES

Major Refernces for Each Section

Technology Description	Sources (from list below) 1 and 6
Performance	Sources 1, 3, and 6
Technology Applicability and Alternatives	Sources 1, 3, and 4
Cost:	Sources 5 and 11
Regulatory/Policy Requirements and Issues	Sources 1, 3, 4, 6, 11, and 12
Lessons Learned:	Sources 2, 4, and 5
Demonstration Site Characteristics	Sources 6, 8, 15, and 17
Technology Description Detail	Sources 1, 6, 14, 15, and 16
Performance Detail	Sources 1, 3, 4, and 6
Commercialization/Intellectual Property	Sources 1, 3, 4, and 7

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This summary was prepared by

CKY Incorporated
Environmental Services

140 E. Division Rd Suite C-3
Oak Ridge, Tennessee, 37830
Contact: Kenneth Shepard (615) 483-4376

in conjunction with:

Stone & Webster Environmental Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

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Colorado Center for Environmental Management
999 18th Street Suite 2750
Denver CO 80202
Contact: Dawn Kaback (303) 297-0180

for:

HAZWRAP

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